DEVELOPING LINKAGES BETWEEN SEDIMENT LOAD AND BIOLOGICAL IMPAIRMENT FOR CLEAN SEDIMENT TMDLs

by Roger A . Kuhnle, Andrew Simon, and Scott S. Knight, USDA-Agricultural Research Service, National Sedimentation Laboratory, P. O. Box 1157, Oxford, Mississippi 38655-1157, email: kuhnle@sedlab.olemiss.edu

Wetlands Engineering & River Restoration Conference 2001
ASCE, August 27-31, 2001, Reno, Nevada

Abstract
Clean sediment has been identified as the largest named pollutant in the 303(d) listed sites in the United States. The methods used by states to list streams as impaired by sediment is variable. Standard scientifically-based assessment tools are needed to determine the likelihood streams are impaired by clean sediments. In this study, linkages were sought between sediment indices and biologic indices for streams with detailed records of flow discharge, suspended sediment transport , and biological data to use as analogues in the evaluation of sites lacking detailed data. Preliminary analyses show that as durations of suspended sediment concentration at or above 1000 mg/l increase the total number of organisms and the number of taxa tend to decrease for benthic organisms. The data for this determination was from streams in the Mississippi Valley Loess Plains in the state of Mississippi.

Introduction
Excessive erosion, transport, and deposition of sediment in surface waters is a major problem in the United States. The 1996 National Water Quality Inventory (Section 305(b) Report to Congress) indicates sediments are ranked as a leading cause of water quality impairment of assessed rivers and lakes. The impact of sediment in many of these listed streams is from too much or too little clean sediment. Clean sediment is defined here as sediment uncontaminated by other substances. Methodologies are needed to evaluate the likelihood that a given stream is impaired by clean sediment and the sediment conditions for an unimpaired stream (reference conditions) are needed to serve as a target for restoration.

It is generally accepted that a significant change in the amount of sediment in the water column or in the movement of the sediment on the bed surface of a stream is detrimental to aquatic organisms. Except in a small number of cases, such as for salmonid fish, the magnitude of the change in suspended sediment or movement of the bed material, necessary to significantly impair the biota is not known. This type of information is necessary to determine whether a given departure of sediment load from a defined stable reference condition is sufficient to impact the designated use of a stream or river. Water quality standards are set by States, Territories, and Tribes. They identify the uses for each water body, for example, drinking water supply, contact recreation (swimming), and aquatic life support, and the scientific criteria to support that use. The Clean Water Act, section 303, establishes the water quality standards and Total Maximum Daily Load (TMDL) programs.

The determination of unimpaired reference conditions and the magnitude of change necessary for impairment due to clean sediment will likely vary in the different physiographic or eco-regions of the country. A related study (Simon et al., 2001) using data collected by the United States Geological Survey (USGS), has shown that sediment yields vary dramatically in different physiographic provinces of the United States. Reference conditions of undisturbed or stable streams and the ability of the biota to handle changes in the sediment regime will likely also vary with physiographic region.

The linkage between changes in the sediment regime of a stream and the impact on the biota is poorly known for streams in most areas of the country. Knowledge of this linkage, however, is essential for the assessment of streams suspected to be affected by clean sediment and for the development of clean sediment TMDLs. The United States Environmental Protection Agency (USEPA) has defined a seven-step procedure for the development of clean sediment TMDLs in impacted waterbodies (USEPA, 1999a, Fig. 1-2). This study will present data towards defining the first two steps of the TMDL process for clean sediments: Problem Identification, and Development of Numeric Targets. Kuhnle and Simon (2000, 2001) have outlined a methodology to identify streams impacted by sediment and a methodology to develop numeric targets for impairment. In this study, linkages between suspended sediment variables (frequency and duration) and indices of biological assessment (USEPA, 1999b) were sought for streams in the Demonstration Erosion Control (DEC) watersheds of Mississippi. Detailed flow discharge and suspended sediment transport data have been collected at all of these sites and it is the long term goal of this research to develop methodologies to assess the likelihood that a site is impaired because of clean sediments over the United States without requiring each site have an extensive record of sediment transport and flow measurements.

Study Sites

The study sites were located on DEC watersheds in the northern half of the state of Mississippi. The DEC project was organized as a cooperative project involving the United States Department of Agriculture (USDA) Natural Resources Conservation Service, USDA - Agricultural Research Service, National Sedimentation Laboratory (NSL), US Army Corps of Engineers, Vicksburg District, and the USGS Mississippi Office. The main goals of the DEC project were to develop and implement new erosion-control techniques for implementation and testing on the highly erodible Mississippi Valley Loess Plains in the state of Mississippi (Little and Murphey, 1981; Cooper and Knight, 1986). Detailed records of flow discharge and suspended sediment transport have been collected by the USGS for eleven of the sites and one was collected by the NSL (Table 1). The periods of record at the sites range from 6 to 16 years and the number of sediment samples from 91 to 3686. The location of the data collection sites and the level III eco-regions of Mississippi are shown in Figure 1. Most of the sites are in the Mississippi Valley Loess Plains eco-regions (Fig. 1).

Table 1. Study Sites and Years of Record.

Name	USGS station ID	years of record	no. of suspended sed. samples
Abiaca Creek at Cruger, MS	07287160	1992-1999	1128
Abiaca Creek near Seven Pines, MS	07287150	1992-1999	3686
Batupan Bogue at Grenada, MS	07285400	1986-1993	393
Fannegusha Creek near Howard, MS	07287355	1987-1999	933
Goodwin Creek Station 2 near Batesville, MS	na.	1981-1996	962
Harland Creek near Howard, MS	07287404	1987-1993	413
Hickahala Creek near Senatobia, MS	07277700	1986-1993	476
Hotophia Creek near Batesville, MS	07273100	1986-1991	207
Long/Peters Creek near Pope, MS	07275530	1987-1993	223
Otoucalofa Creek Canal near Water Valley, MS	07274252	1986-1993	91
Topashaw Creek near Calhoun City, MS	07282100	1988-1993	682
Yalobusha near Calhoun City, MS	07282000	1988-1993	504

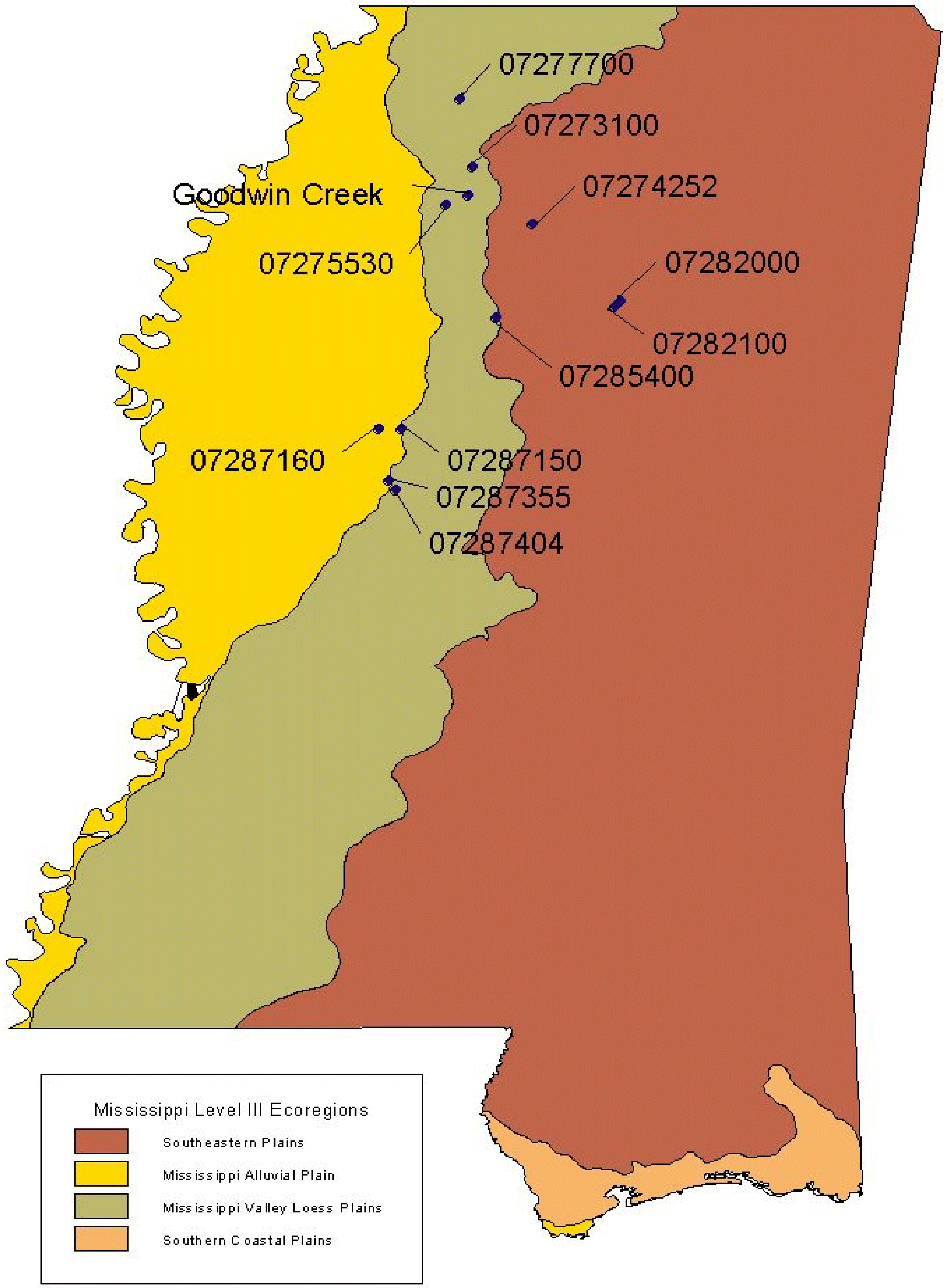

Figure 1: Locations of Study Sites

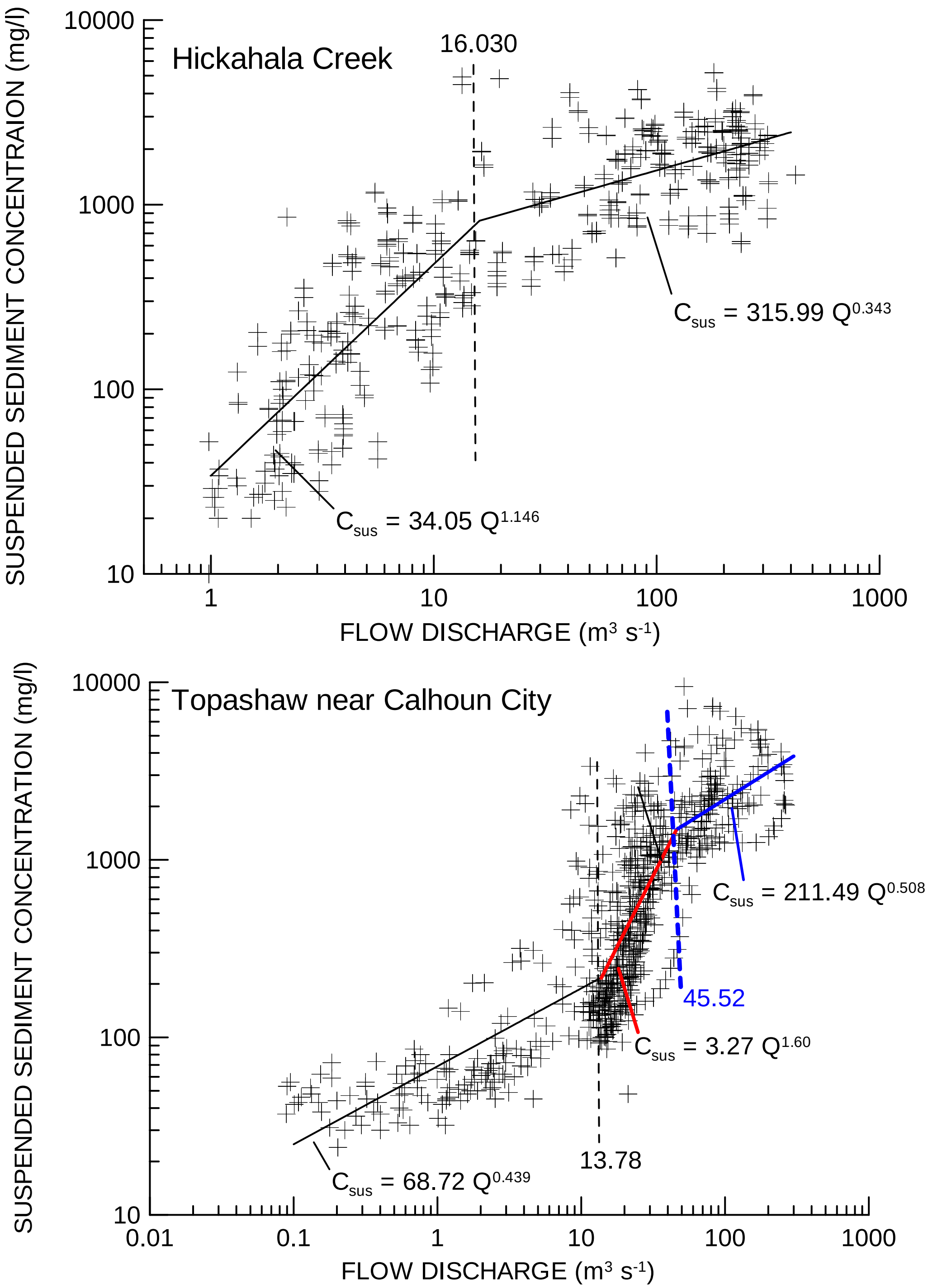

Figure 2. Suspended sediment rating curves using multiple power equations for Hickahala Creek (top), and Topashaw Creek (bottom).

Analysis of Data
The flow data from all sites except Goodwin Creek station 2, consist of stage values collected every 15 minutes at USGS gauging stations. The stage values were converted to discharge using a calibrated relation. The flow data from Goodwin Creek station 2 consists of break point stage data collected in a supercritical flow flume (Bowie and Sansom, 1986). When flows were changing rapidly, stage data was collected at one minute intervals. When flow rates were steady, stage was collected as infrequently as every 24 hours. Stage data was converted to discharge using a calibrated relation. Frequencies of the discharge data were calculated using 35 classes defined by base 10 logarithms (Searcy, 1959). The instantaneous annual peak discharge for each site was calculated from the annual series of peak flows (Haan, 1977).

The sediment transport data from the 11 U.S. Geological Survey sites consist of all sizes of the sediment suspended in the water. These samples were collected using standard USGS collection procedures (Edwards and Glysson, 1999). The sediment transport samples collected at Goodwin Creek station 2 were collected using a strut-mounted DH-48 sampler through the entire flow depth at the downstream end of a supercritical flow structure (Willis et al., 1986). Power functions were fit to the suspended sediment and flow discharge data pairs. Where necessary multiple power functions were used to accurately represent the trend of the data (Fig. 2).

Using the flow and sediment records (Table 1), frequency and duration for sediment concentrations of a given magnitude were calculated. This was accomplished by using the power function rating curves to calculate sediment concentration for a given flow. Durations of a given sediment concentration were calculated similarly by first calculating the duration of a given flow using the time records and then converting it to a sediment concentration using the relations between flow and concentration.

Sediment Frequency and Duration
Frequency and duration values of suspended sediment were calculated for each of the twelve sites (Table 2). Despite the similarities of these streams, appreciable differences in frequency and duration values were found. Suspended sediment concentrations of 1000 mg/l or greater were present for between 0.4 to 10 percent of the time annually , with the expected annual duration of 1000 mg/l ranging from 0 to 3044 minutes. The ranges in the suspended sediment concentration and duration at the one year flow had similar magnitudes. Another useful way to compare the durations of sediment concentrations at the study sites is shown in Figure 3. These curves show the expected annual durations (minutes) for a wide range of sediment concentrations. The location of curves in duration versus sediment concentration space (Fig. 3) may be important for determining whether a given stream is impaired by clean sediment.

Relating Sediment Variables to Biologic Indices
The relation, if any, between the sediment parameters contained in Table 2 and several indices describing the community of benthic invertebrates were explored using scatter plots. The eight sites from this study which have biologic data available are indicated in Table 2. The list of the benthic indices is contained in USEPA (1999b). The only two benthic indices which yielded

evidence for a relation were number of taxa and total number of organisms (Fig.4). The best sediment variable to relate to these indices was determined by inspection to be the duration above 1000 mg/l.

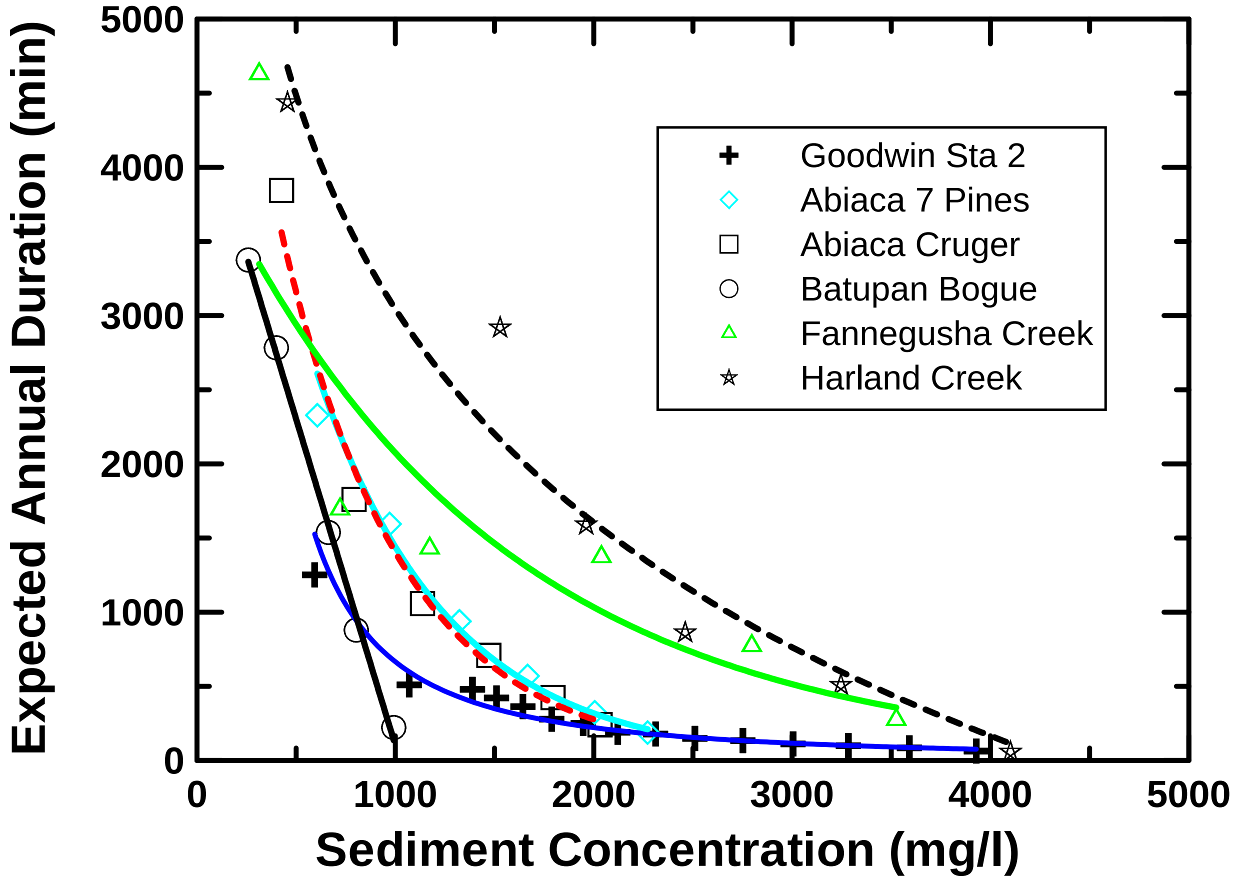

Figure 3. Curves of annual duration versus sediment concentration for several of the streams demonstrate the variability of this relation.

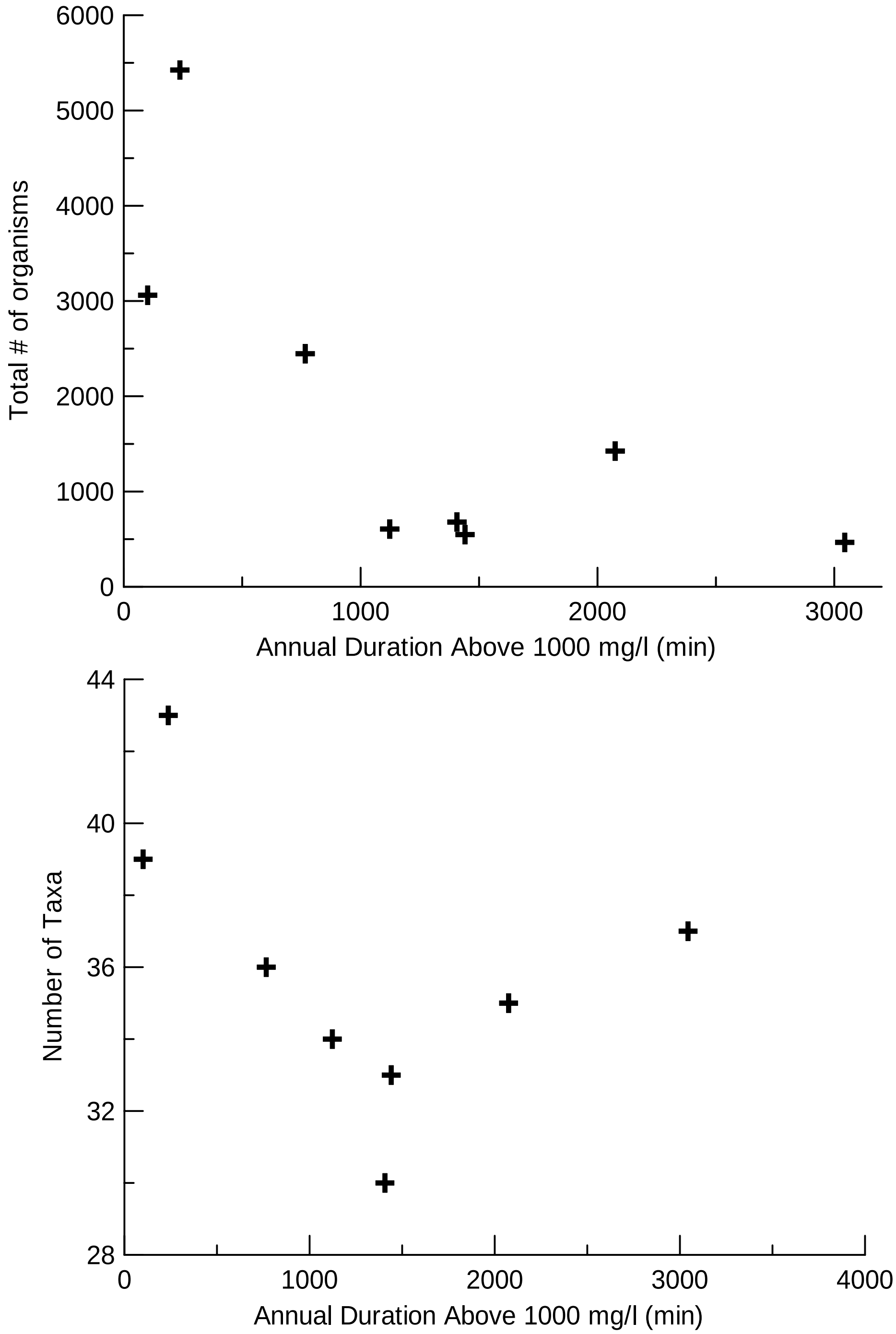

Figure 4. Total number of organisms (top) and number of taxa (bottom) as related to annual duration above 1000 mg/l.

Table 2. Frequency and Duration values for the study sites.
A. - Fraction of time suspended sediment equals or exceeds 1000 mg/l.
B. - Expected annual continuous duration of suspended sediment at 1000 mg/l or greater (min).
C. - Concentration of suspended sediment at 1.0 year flow (mg/l).
D. - Expected duration of 1 year flow (min).
E. - Stage of channel evolution (Simon and Hupp, 1989).
* - indices available on benthic community at these sites.

Name	A.	B.	C.	D.	E.
Abiaca Creek at Cruger, MS *	0.015	1407.	2032.	242.	5
Abiaca Creek near Seven Pines, MS*	0.019	1441.	2272.	188.	5
Batupan Bogue at Grenada, MS*	0.032	101.	992.	222.	5
Fannegusha Creek near Howard, MS*	0.060	2075.	3525.	276.	5
Goodwin Creek Station 2	0.012	668.	3591.	85.	5
Harland Creek near Howard, MS*	0.100	3044.	4043.	57.	5
Hickahala Creek near Senatobia, MS	0.030	1396.	2070.	58.	5
Hotophia Creek near Batesville, MS*	0.008	237.	1405.	111.	5
Long/Peters Creek near Pope, MS*	0.030	1123.	1664.	275.	5
Otoucalofa Creek Canal near Water Valley,MS*	0.090	766.	1548.	465.	5
Topashaw Creek near Calhoun City, MS	0.019	354.	1071.	342.	5
Yalobusha near Calhoun City, MS	0.004	0.	320.	604.	5

Discussion and Future Work

Figure 4 demonstrates evidence for a relation between number of taxa and the total number of organisms to the annual duration of suspended sediment above 1000 mg/l. This relation is remarkable in light of the complexity of the physical and biological systems in these streams. In future studies, frequency and duration of bed material movement and indices for other organisms, such as fish, will be considered. It is possible that vertebrates that live in the water column will be more susceptible to changes in suspended sediment concentrations and benthic dwelling organisms will be more susceptible to instability of the bed material. Identification of the critical combinations of magnitude, frequency, and duration for sediment related indices that cause impairment in streams of the major eco-regions of the country is the long term goal of this study.

References

Bowie, A. J., Sansom, O. W. (1986). Innovative techniques for collecting hydrologic data. Fourth Federal Interagency Sedimentation Conference, Las Vegas, Nevada, p.1-59 - 1-69.

Cooper, C. M., Knight, S. S. (1986). Status Report: Ecological aspects - Demonstration Erosion Control Project in the Yazoo basin. Mississippi Chapter American Fisheries Society 11: 20-26.

Edwards, T. K., Glysson, G. D. (1999). "Field methods for measurement of fluvial sediment." U. S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C2, 89 pp.

Haan, C. T. (1977). Statistical Methods in Hydrology. The Iowa State University Press, Ames, Iowa, 378 p.

Kuhnle, R. A., Simon, A. (2000). Evaluation of Sediment Transport Data for Clean Sediment TMDLs. USDA-ARS, National Sedimentation Laboratory Report 17.

Kuhnle, R. A., Simon, A. (2001). Evaluation of sediment transport data for clean sediment TMDLs. Seventh Federal Interagency Sedimentation Conference, Reno, Nevada.

Little, W.C., Murphey, J. B. (1981). Evaluation of streambank Demonstration Erosion Control projects in the bulffline of northwestern Mississippi; Project Objective 2, Appendix A, Stream Channel Stability, Report to US Army Corps of Engineers, Vicksburg District, 342 pp.

Searcy, J. K. (1959). Flow-duration curves. Manual of Hydrology: Part 2. Low-flow Techniques. United States Geological Survey, Water-Supply Paper, 1542A, 33 p.

Simon, A., Kuhnle, R. A., Knight, S. S., Dickerson, W. (2001). Critical issues for determining "reference" and enhanced rates of sediment transport for use in developing clean-sediment TMDLs, Wetlands Engineering and River Restoration Conference, ASCE, Reno, NV; August, 2001

Simon, A., and Hupp, C. R. (1986). Channel evolution in modified Tennessee streams. Fourth Federal Interagency Sedimentation Conference, March, 1986, Las Vegas, Nevada, v. 2, p. 71-82.

USEPA, (1999a). Protocol for developing sediment TMDLs. United States Environmental Protection Agency, Office of Water, Washington DC, EPA 841-B-99-004.

USEPA (1999b). Rapid bioassessment protocols for use in wadeable streams and rivers. United States Environmental Protection Agency, Office of Water, Washington DC, EPA 841-B-99-002.

Willis, J. C., Darden, R. W., and Bowie, A. J. (1986). Sediment transport in Goodwin Creek. Fourth Federal Interagency Sedimentation Conference, Las Vegas, Nevada, p.4-30 - 4-39.