EVALUATION OF THE IMPORTANCE OF CHANNEL PROCESSES IN CEAP-WATERSHED SUSPENDED-SEDIMENT YIELDS

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Abstract: Sediment is one of the principle pollutants of surface waters of the United States. Efforts by the U.S. Department of Agriculture to quantify and control sediment erosion have historically focused on fields and upland areas. There is a growing body of evidence in agricultural areas of the mid-continent that the locus of sediment erosion has shifted from fields and uplands to edge of field gullies and channels. This is due in part to successful conservation efforts and the natural attenuation of erosion processes with time. Sediment, eroded historically from fields and uplands, was deposited in valley bottoms, filled channels, and accumulated on flood-plain surfaces, causing severe drainage problems. To convey floodwaters and to alleviate flooding problems, channels throughout the mid continent were dredged and straightened, resulting in de-stabilization of entire river systems, severe bank erosion and dramatic increases in erosion rates. This rejuvenation of channel systems results in a systematic series of processes and channel forms that can be identified as *stages of channel evolution*. Today, these channel-erosion processes are still active and can account for up to 85% of the suspended-sediment load in streams, much of this from streambank failures. A reconnaissance study of about 2,500 km of streams in western Iowa showed that 80% of the observed stream reaches were experiencing streambank failures (Hadish, 1994). Similar studies in southeastern Nebraska and western Tennessee showed that about 75% and 60% of stream reaches had unstable streambanks, respectively (Simon and Rinaldi, 2000; Bryan et al., 1995).

Rapid geomorphic assessments (RGAs) of benchmark watersheds in the Conservation Effects Assessment Program (CEAP) are used to determine the degree of instability and stages of channel evolution throughout the channel systems. The distribution of stages throughout the channel network identify local versus systematic disturbances and whether channels are important contributors of sediment. Stable, reference conditions are identified from stages I and VI and used as a means of comparing suspended-sediment yield data from the CEAP watersheds to regional values. Data from more than 2,900 sites across the United States were analyzed in the context of estimating flow and suspended-sediment transport conditions representing average, annual, and at the 1.5-year recurrence interval ($Q_{1.5}$) discharge. Data were sorted into the 84 Level III ecoregions to identify spatial trends in suspended-sediment concentrations and yields. Suspended-sediment yields for stable streams are used to determine “background” or “reference” sediment-transport conditions and to compare with values obtained from the monitored CEAP watersheds.

INTRODUCTION

The Conservation Effects Assessment Program is a collaborative effort between the USDA-Natural Resources Conservation Service, USDA-Agricultural Research Service (ARS) and other agencies and academic institutions. This national research effort aims to provide long-term, coordinated research across a range of hydrologic and agronomic settings for the purpose of improving models for national assessment and to develop policy planning tools. Twenty-four watersheds were initially selected for detailed investigation: 12 ARS Benchmark Watersheds and 8 NRCS Special Emphasis Watersheds and 4 Special Grants Watersheds (Figure 1). The impetus for this work stems from the need to evaluate the natural resource effects of conservation practices in a unified way. Historically these agencies have largely focused on issues involving the movement and transfer of water, pollutants and sediment attributed to “watershed” processes, or what has come to mean upland- and field-processes only. Channels, however, can be considered the “information highway” of the watershed, responsible for the transfer of energy and materials through and out of the watershed. This is particularly true for sediment and therefore requires attention.

Sediment is one of the principle pollutants of surface waters of the United States and has been positively correlated with negative impacts on aquatic ecosystems (Newcombe and MacDonald, 1991; Newcombe

Figure 1 CEAP research watersheds. Red denotes ARS Benchmark Watersheds; blue denotes NRCS Special Emphasis Watersheds; green denotes Special Grants Watersheds.

and Jensen, 1996; Kuhnle et al., 2001; 2002). Suspended sediment parameters have also been related to indices of biotic impairment. Efforts by the U.S. Department of Agriculture to quantify and control sediment erosion have historically focused on fields and upland areas.

There is a growing body of evidence in agricultural areas of the mid-continent that the locus of sediment erosion has shifted from fields and uplands to channels and edge of field gullies (Trimble, 1983; Simon and Rinaldi, 2000). This is due in part to successful conservation efforts (Trimble and Lund, 1983) and the natural attenuation of erosion processes with time. Sediment, eroded from fields and uplands, is deposited in valley bottoms, fills channels, and accumulates on flood-plains, causing severe drainage problems. To convey floodwaters and alleviate flooding problems, channels throughout the mid continent were dredged and straightened, resulting in de-stabilization of entire river systems and dramatic increases in erosion rates. This rejuvenation of channel systems results in a systematic series of processes and channel forms that can be identified as *stages of channel evolution* (Schumm et al., 1984; Simon and Hupp, 1986; Simon, 1989; Figure 1). A reconnaissance study of about 2,500 km of streams in western Iowa showed that 80% of the observed stream reaches were experiencing streambank failures (Hadish, 1994). Similar studies in southeastern Nebraska and western Tennessee showed that about 75% and 60% of stream reaches had unstable streambanks, respectively (Simon and Rinaldi, 2000; Bryan et al., 1995). Today, these channel-erosion processes, which include streambank failures, are still active and contribute a large proportion of sediment to the suspended load in streams. To evaluate the contributions of sediment from the landscape and stream banks to the suspended load, the innovative techniques discussed below are required.

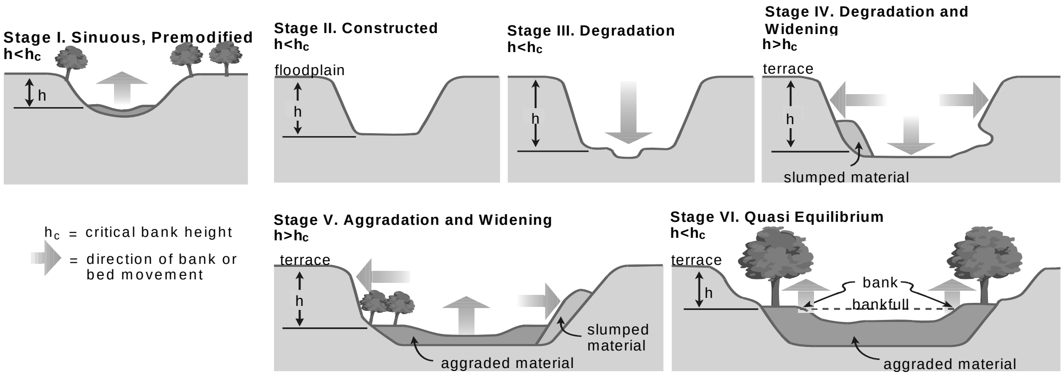

Figure 2 Six stages of channel evolution (from Simon and Hupp, 1986 and Simon, 1989) identifying Stages I and VI as "reference" conditions for Level III ecoregions.

Suspended-Sediment Concentrations, Loads and Yields at the National Scale: Recent research has shown that suspended-sediment yields can be distinguished by ecoregion for stable ("reference" conditions) and unstable streams differentiated by stage of channel evolution (Simon et al., 2002, 2004; Figure 2). This is accomplished using a three-step process:

1. Historical flow and sediment-transport data from sites across the United States are sorted by Ecoregion (Figure 3) and used to develop sediment-rating relations (Figure 4) and loads at the effective discharge by determining the $Q_{1.5}$ from peak-flow data (Figure 5). Mean-daily flow data are used with the transport relation to determine average annual suspended-sediment loads. Annual loads and those at the $Q_{1.5}$ are divided by drainage area to normalize the data for means of comparing values within a given ecoregion.

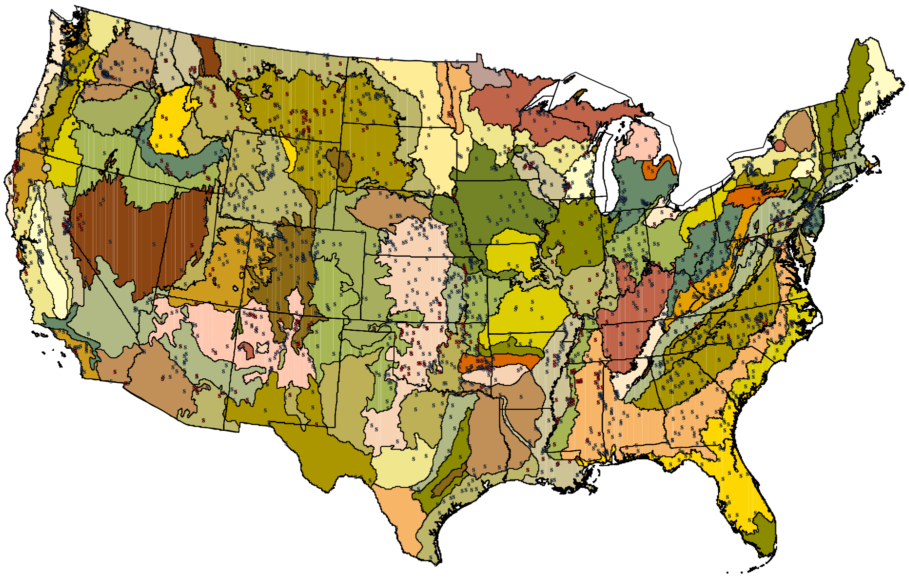

Figure 3 Map of Level III ecoregions of the continental United States showing locations of historical flow and suspended-sediment data.

2. Rapid geomorphic assessments and analysis of gaging-station records are used to determine the relative stability and stage of channel evolution of the site for the purpose of determining whether the calculated suspended-sediment loads reflect "natural", "background", or "reference" conditions, or whether they represent unstable, impacted conditions.

3. Suspended-sediment yield data for an ecoregion are then sorted into “reference” and unstable sites and plotted as histograms to determine the distribution of yields. A “reference” suspended-sediment yield is then determined as either the median value or as the inter-quartile range of the “reference” data (Figure 6). Results have provided an estimate of the range of suspended-sediment yields and concentrations for ecoregions of the continental United States (Figure 7).

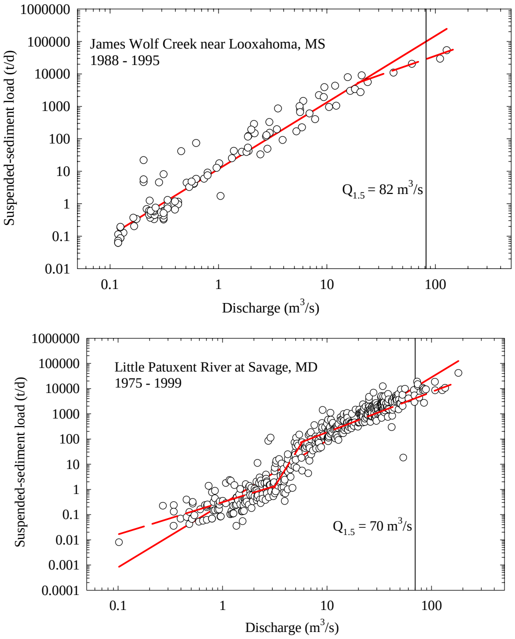

Figure 4 Suspended-sediment transport relation derived from historical data. Note the use of two- and three-stage relations to minimize error at high flows.

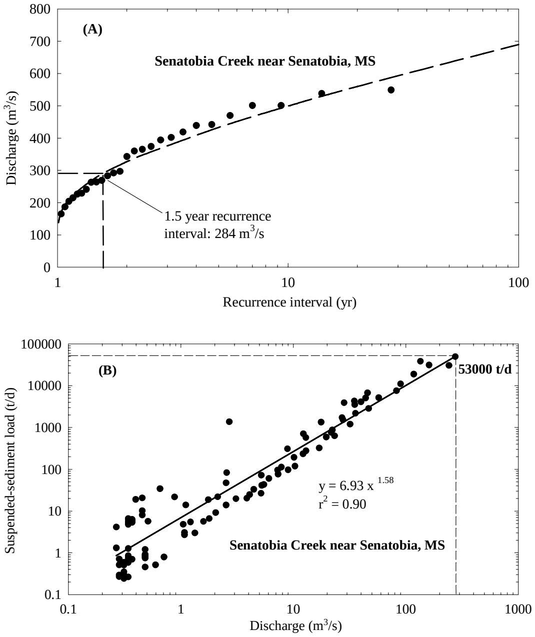

Figure 5 Determination of the $Q_{1.5}$ from peak flow data (A) and application to the transport relation for that site (B).

In addition, naturally occurring radionuclides (^{7}Be and ^{210}Pb) have been used as tracers to provide information regarding the sources of the sediment transported in streams (Wilson et al., 2003; 2005). Proportions of the two radionuclides can be used to differentiate between sediment delivered from the landscape and from streambank failures, gullies, or re-suspended bed material in the suspended sediment due to different half-lives and erosion mechanisms in each source area (Figure 3). They further provide a unifying set of measurements and analyses by which to compare sediment-transport rates and sources. During the 2004 CEAP meeting in Irving, Texas, 11 of the 12 CEAP watersheds (Beasley Lake to be excluded) representatives expressed needs for evaluation of channel erosion processes (Table 1). A number of these representatives indicated that they could aid in supporting this research effort to some degree.

Because the evaluation of conservation measures and best management practices in the CEAP watersheds must be aimed at addressing critical erosion sources, it is important to identify to what degree sediment yield from these watersheds are affected by both upland and channel erosion and if those loads represent impacted channel conditions.

APPROACH

The research approach includes three distinct phases of work that will provide parallel lines of evidence regarding magnitudes and sources of sediment emanating from 11 CEAP watersheds. These work phases follow the natural order of landscapes events from uplands through channels to watershed outlet:

1. Reconnaissance of trunk stream and major tributary channels using rapid geomorphic assessments (RGAs) to determine relative channel stability and stage of channel evolution;

2. Analysis of sediment-transport and flow data from the specific watershed and associated Level III ecoregion to compare rates of sediment transport between the watershed and stable and unstable streams in the ecoregion and to calculate magnitude, frequency, and duration of sediment concentrations; and

3. Quantification of the relative proportion of sediment from different sources in the suspended load of streams during runoff events using ^{7}Be and ^{210}Pb.

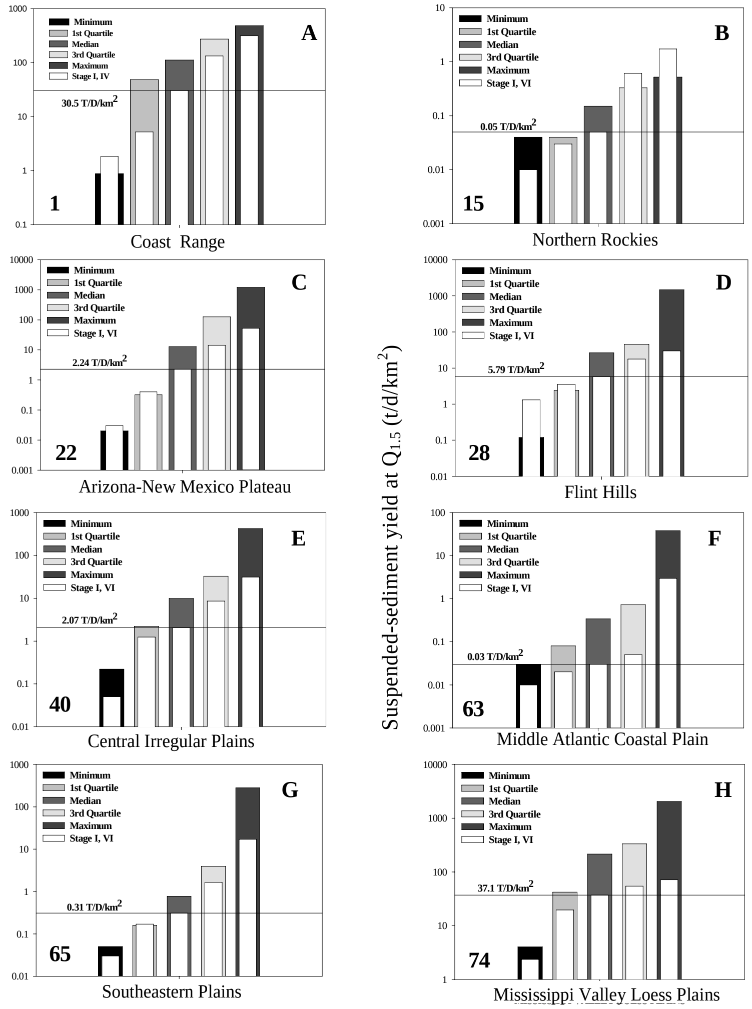

Figure 6 Examples suspended-sediment yield distributions (quartile values) for a range of ecoregions showing differences between stable and unstable sites. Numbers denote Level III ecoregion number.

Rapid geomorphic assessments:
Relative channel stability and stage of evolution are determined by aerial and ground reconnaissance of main stem and tributary channels using diagnostic criteria of channel form to determine dominant channel processes. Rapid geomorphic assessments (RGAs) are conducted throughout the channel network and include a survey of channel gradient, bed-material sampling, photographs and an evaluation of attributes of channel erosion and deposition. A semi-quantitative index of channel stability is calculated by summing values of objectively ranked criteria such as type of bed material, degree of incision, existence and type of bank erosion, extent of reach experiencing streambank failures, prevalence of edge of field gullies, extent of bank and bar deposition, woody-vegetative cover, and stage of channel evolution. Mapping the channel-stability index, stage of channel evolution and stability conditions provides a means of determining the magnitude and extent of channel instabilities and erosion sources.

Actual and “reference” sediment-transport rates Annual suspended-sediment yields and those at the $Q_{1.5}$ (effective discharge) have been calculated for sites with USGS historical data in the ecoregion that contains each of the CEAP watersheds (Simon et al., 2004). Analysis of USGS discharge-measurement data combined with RGAs at sites that have not been previously visited in the appropriate ecoregions will be used to distinguish between stable and unstable conditions during the period of sediment sampling. Ranges of suspended-sediment yields for stable (“reference”) and unstable sites will then be determined by sorting the data by stage of channel evolution. Flow and sediment-transport data available from CEAP-watershed gages will be used to calculate “actual” sediment-transport rates and compared with “reference” values to determine if the CEAP-watershed streams have been impacted by sediment. The same technique will be used to determine whether coarse-bedded streams are impacted by fine-sediment deposition, using the percentage of bed material finer than 2mm. Flow and sediment-transport data will also be used to calculate magnitude, frequency, and duration of various concentrations of suspended sediment to distinguish between stable and impacted conditions.

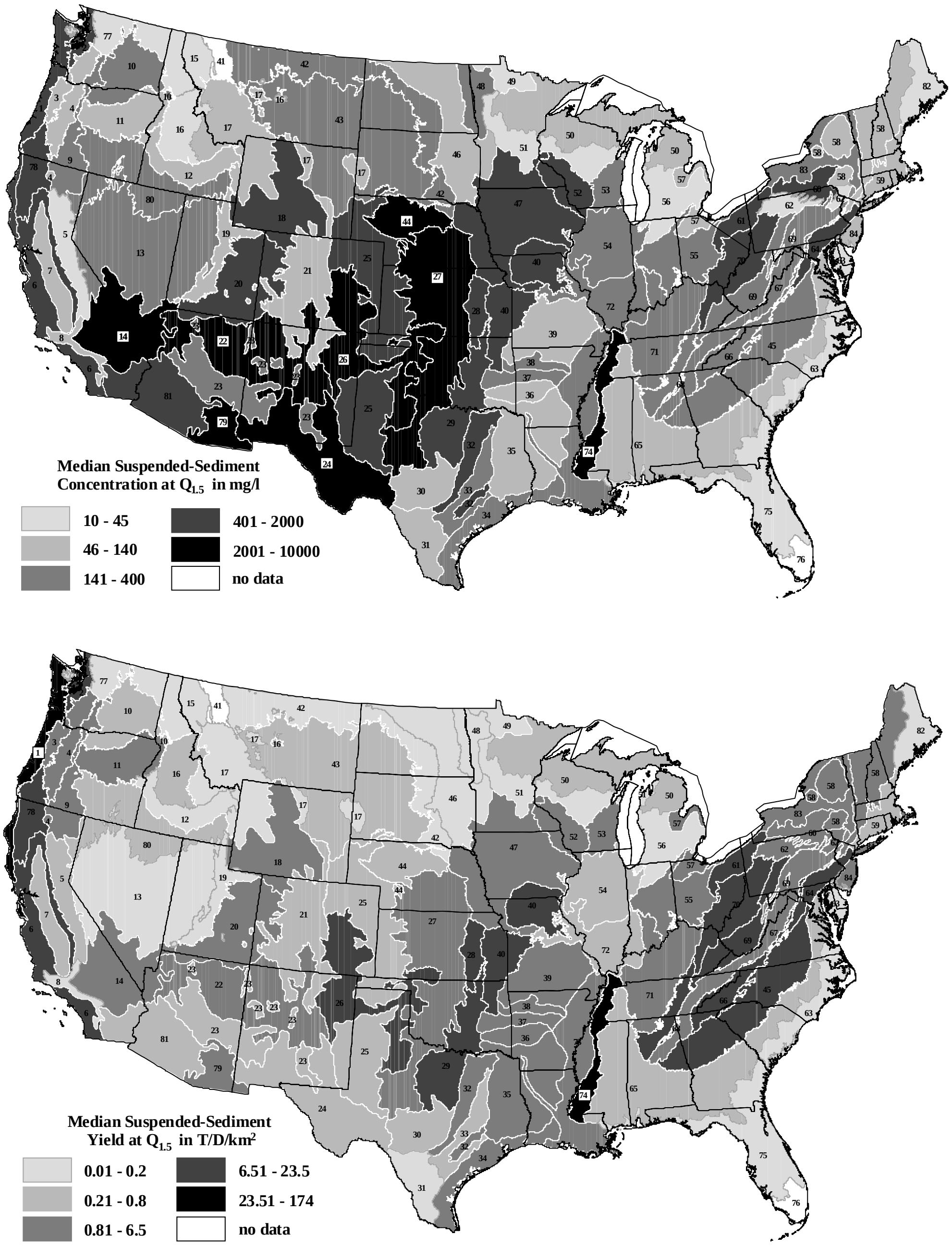

Figure 7 Distribution of median suspended-sediment concentrations and yields at the $Q_{1.5}$ for Level III ecoregions of the continental United States.

Sediment source areas: Activities of ^{7}Be and ^{210}Pb from soil, bank, and suspended sediments will be collected in the CEAP watersheds to determine the percent contribution from landscape erosion and bank collapse. Collection of the soil profiles of ^{7}Be and ^{210}Pb will focus in agricultural fields currently in use. Sampling of streambanks will require long cores to determine background activities of the radionuclides in the banks. Suspended-sediment samples will be collected during runoff events at the head and mouth of the designated stream reach. Sampling will be evenly spaced over the hydrograph. At least 1 g of sediment is required. Sampling during runoff events will also include collection of precipitation. Gamma spectroscopy will be used to determine the activities of ^{7}Be and ^{210}Pb at the NSL. High radionuclide activities suggest a large proportion of recently eroded landscape-derived material. Conversely, lower activities in the suspended sediment suggest dilution by bank material. A simple two-end member-mixing model will determine the relative contribution of each source to the total sediment load. The radionuclide signature of suspended sediments would lie roughly along the mixing line between the signatures of the two end-member sources of sediment (Figure 8).

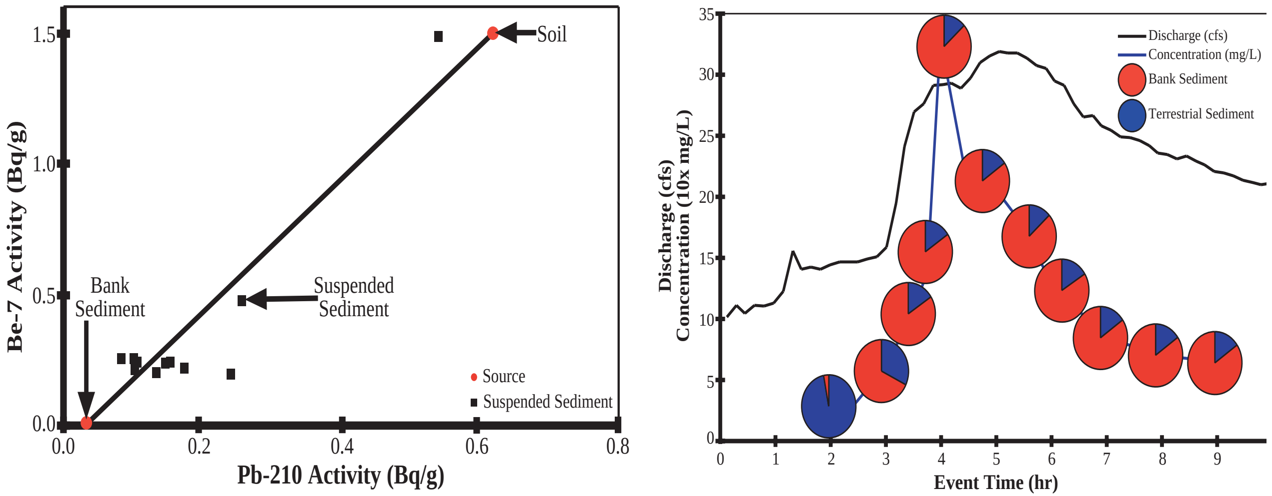

Figure 8 Example results from Goodwin Creek, MS showing ratios of ^{7}Be and ^{210}Pb in streambank, soil and suspended-sediment samples (A) and the percentage of eroded sediment emanating from streambank (red) and terrestrial (blue) erosion using ratios of ^{7}Be and ^{210}Pb in suspended sediment (B). From Wilson and Kuhnle (2006).

Table 1 Status of NSL work to determine suspended-sediment yields and “reference” conditions for Level III ecoregions encompassing the CEAP watersheds.

CEAP Watershed	Ecoregion #	Ecoregion Yields	“Reference” Yields	Watershed Interest
Upper Washita River, OK	27	Completed	Partial	Yes
Goodwin Creek, MS	74	Completed	Completed	Yes
Yalobusha River, MS	65	Completed	Completed	Yes
Beasley Lake	73	Completed	Completed	No
South Fork Iowa River, IA	47	Completed	Partial	Yes
Walnut Creek, IA	47	Completed	Partial	Yes
Town Brook, NY	58	Completed	Not Started	Yes
Upper Big Walnut Creek, OH	55	Completed	Not Started	Yes
Mark Twain Reservoir, MO	40	Completed	Completed	Yes
Little River, GA	45	Completed	Completed	Yes
Upper Leon River, TX	29	Completed	Partial	Yes
St Joseph River, IN	55	Completed	Not Started	Yes

EXPECTED RESULTS AND PRODUCTS

Results of the proposed cross-location research will provide a quantitative evaluation of the role of channel processes in CEAP watersheds. Series of maps will be produced distinguishing critical erosion areas in the stream network and determination of local versus system-wide instabilities. Comparison of watershed sediment yield with those for stable sites in the associated ecoregion will provide a basis to determine the relative magnitude of erosion-related sediment problems in the CEAP watersheds. The proportions of sediment eroded from fields and streambanks will be evaluated using radionuclide signatures and will assist in efficient development of management practices.

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