DETERMINATION OF SEDIMENT SOURCES ON THE CEAP BENCHMARK WATERSHEDS

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Abstract: As part of the Conservation Effects Assessment Program (CEAP), 12 watersheds across the country have been designated as CEAP benchmark watersheds. These watersheds were chosen to evaluate the effectiveness of the conservation practices applied under various landscape and agricultural conditions in different parts of the country. Goodwin Creek, located in the north central part of Mississippi, is one of the CEAP benchmark watersheds where the effects of land use and management practices on sediment transport have been studied since 1982. Recently, technology to differentiate the source of fine sediments in the suspended load of streams using naturally occurring radionuclides has been applied within this watershed. Preliminary data from Goodwin Creek show that fine sediment is predominantly derived from the land surface during the initial part of a runoff event. The latter parts of the same runoff event indicated that the sources of fine sediment shifted to predominantly channel bank sources. Further measurements will provide information on the variations of sediment sources of fine sediments during different parts of the year and for different magnitude flows. This technique will be applied to other CEAP benchmark watersheds with the cooperation of the researchers from those watersheds. Knowledge of the sources of sediment in the different benchmark watersheds will provide critical information regarding sediment problems and the types of management practices that will most likely be effective in rectifying these problems.

INTRODUCTION

The 2002 Farm Bill and CEAP: Although erosion of surface soils from the landscape is a natural process, it has been considerably augmented by agricultural practices. This accelerated loss of topsoil can significantly lower crop yields. Moreover, anthropogenically increased erosion of fine sediment with sorbed nutrients and contaminants will have detrimental effects on the receiving waters below agricultural fields. These contaminants also can be transmitted through the food chain, causing further degradation of agricultural ecosystems.

The Farm Security and Rural Investment Act of 2002, more commonly known as the 2002 Farm Bill, was designed to curb increased soil erosion from agricultural fields by providing financial incentives for the implementation of conservation practices. The bill significantly increased overall spending for programs that support conservation of agricultural lands compared to previous initiatives. In addition, the 2002 Farm Bill expanded older programs and created new ones to promote Best Management Practices (BMPs). Understanding land use change and its effect on soil erosion is a crucial but daunting task for the development of efficient BMPs.

In response to the 2002 Farm Bill, the United States Department of Agriculture (USDA) created the Conservation Effects Assessment Project, or CEAP, to evaluate the environmental benefits of conservation practices. One of the primary objectives of CEAP is to develop a set of regional watershed assessment models that can be used to address benefits of conservation practices and other environmental issues in the major agricultural regions of the nation and for use in future national assessments (USDA-ARS, 2005). Several valuable models currently exist which attempt to evaluate the contributions of sediment from various sources within a watershed. However, limited data are available to validate these models. CEAP promises to provide validation data sets for these models that will be useful at the watershed and regional scales to evaluate the benefits associated with conservation practices and the effectiveness of current and proposed management practices (USDA-ARS, 2005).

The present study will assist CEAP in reaching the above objective. The ability to accurately assess the delivery of sediment from different parts of the watershed to the suspended load of a stream allows for better management of agricultural fields. An accurate determination of soil loss is crucial for validation of the models developed to evaluate conservation practices.

Project Objective: Agricultural fields are often considerable suppliers of fine sediment to the suspended load of streams because tillage practices loosen top soil making it more susceptible to erosion. Other processes, including channel bank erosion and resuspension of bed sediment, which are not directly affected by anthropogenic influences, can also contribute to the fine sediment load of streams. Understanding the roles of these different processes controlling sediment transport within a watershed will provide valuable information for evaluating the effectiveness of BMPs. The ability to differentiate sediment contributed from different source areas is an important first step in calculating the relative contribution of different sources.

Each source of sediment must have a unique signature relative to the others to properly differentiate it from other sources and to quantify its contribution to the suspended load. Previous sediment sourcing studies have shown that the degree of precision in identifying major contributors of sediment and calculating their delivery is directly related to the number of sediment properties compared between the different source areas (Peart and Walling, 1986 and Walling and Woodward, 1992). However, the work load of the project also substantially increases with the number of studied sediment characteristics.

This study was developed to provide a simpler method of differentiating sediment from multiple sources within a watershed by examining only the activities of two naturally occurring radioisotopes, ^{7}Be and ^{210}Pb$_{xs}$, and their ratio relative to one another. The simplified method does limit the precision of source identification. This method will provide only a relative contribution between eroded surface soils and collapsed bank sediment or resuspended bed material in the suspended load of a small stream during runoff events. The knowledge gained is extremely valuable for the validation of watershed assessment models developed by the USDA.

This paper will develop the novel method, which uses ^{7}Be and ^{210}Pb$_{xs}$ for evaluating relative contributions of fine sediment from different source areas within agricultural watersheds, and its application to several agricultural systems identified by CEAP as benchmark watersheds. The theory behind the study and the methods used to conduct the research will be presented. Analysis of a case study at Goodwin Creek, MS, will be presented in an accompanying paper.

BACKGROUND

This study is designed to quantify the proportion of eroded surface soils relative to contributions from collapsed bank material and/or resuspended bed sediment in the fine suspended sediment load of streams within CEAP benchmark watersheds following runoff events using ^{7}Be and ^{210}Pb$_{xs}$. Each source material must have a unique radionuclide signature relative to the other in order to quantify the contributions from the different source areas to the suspended sediment. Fallout radionuclides, namely ^{7}Be ($t_{1/2}$ = 53.3 days) and ^{210}Pb$_{xs}$ ($t_{1/2}$ = 22.3 years), may provide the characteristic signature to differentiate sediments transported through streams. The two radionuclides relative to one another can be used to differentiate sediment sources due to differences in half-lives or erosion processes (Wilson, 2003; Matisoff et al., 2005 and Wilson et al., 2005).

The radioisotopes ^{7}Be and ^{210}Pb$_{xs}$, which are attached to aerosol particles in the atmosphere, are delivered to the landscape mainly during precipitation events. The radionuclides quickly and strongly bond to surface soils. The binding nature of fallout radionuclides to sediment limits adsorption to only the finer silt and clay particles. The relatively high activities of ^{7}Be and ^{210}Pb$_{xs}$ in the precipitation decrease as the two radionuclides are mixed with previously delivered ^{7}Be and ^{210}Pb in surface soils, which have undergone radioactive decay resulting in lower activities (Matisoff et al., 2005 and Wilson et al., 2005). Surface soils and absorbed radionuclides are eroded from the landscape as runoff initiates and are transported through streams. The eroded sediment from the landscape still has relatively high activities of ^{7}Be and ^{210}Pb$_{xs}$ because sheet erosion removes only a thin layer (<1 cm) of surface soils, which contains the highest activities of the radionuclides from the strong and rapid bonding nature of the radionuclides (Bonniwell et al., 1999). Moreover, the preferential removal of clay particles that occurs during storm runoff (Rhoton et al., 1979) enriches the radionuclide activity of eroded sediment by concentrating the particles, to which the radionuclides sorb.

As the eroded sediment is transported downstream, sediment from stream banks and the bed are entrained into the flow. Additions of bed and bank material, which have low activities of ^{7}Be and ^{210}Pb$_{xs}$, further decrease the radionuclide activities of the suspended fine sediment (Matisoff et al., 2005 and Wilson et al., 2005). Sediments from the bed have resided there for extended periods without radionuclide replenishment and have undergone substantial decay. Eroded bank sediments also will have relatively low activities of ^{210}Pb$_{xs}$ and ^{7}Be because they receive little atmospheric input due to near-vertical slopes (Whiting et al., 2005). Moreover, stream bank failure typically removes large volumes of material (Thorne, 1992). The high activity sediment from the soils at the top of the collapsed bank is diluted by a much larger volume of low activity sediment from deeper in the collapsed bank.

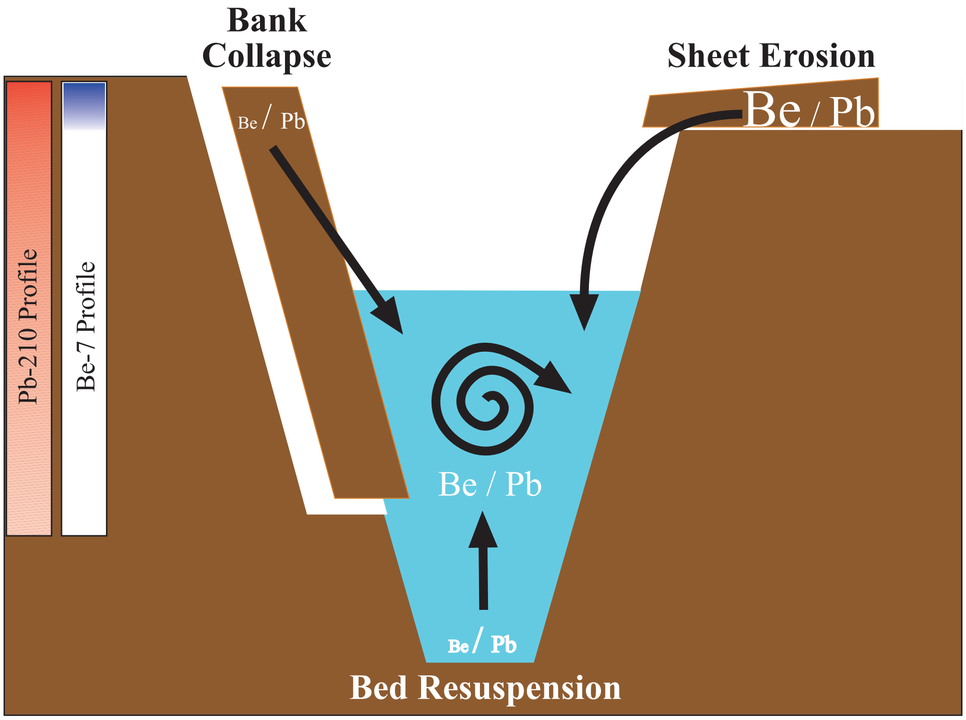

Figure 1 Radionuclide relationship of sources of sediment to suspended load of a stream.

Suspended sediment is a mixture of landscape derived sediment, bed sediment, and bank sediment (Figure 1). However, if one of those sources can be eliminated, as with sand and gravel bed streams, the fine suspended sediment has an intermediate radionuclide signature that is quantified in terms of the relative contribution of landscape derived and bank sediment. 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. The different erosion mechanisms affecting surface soils and bank sediments produce these different signatures.

The suspended sediment in the stream contains a mixture of the eroded surface soils and collapsed bank sediment. The resulting signature of the suspended sediment will reflect the mixture of the surface soils and the bank sediments. A simple two-end member mixing model would determine the relative contribution of each source area to the total fine 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.

METHODS

Study Sites: Activities of ^{7}Be and ^{210}Pb$_{xs}$ from precipitation samples, and soil, bank, and suspended sediments associated with individual runoff events will be collected within CEAP benchmark watersheds. The current CEAP benchmark watersheds (Table 1) are located primarily in the Central and Eastern parts of the United States. The sizes of individual watersheds in CEAP range from <1 km^2 to >8,000 km^2. The watersheds are all agricultural in nature, including mostly row crop farming, pastures, and feed lots. Nearly every watershed cites excess sediment, nutrients, and pesticides in storm runoff as chronic problems in the watershed. To counter these issues, several different BMPs have been implemented in these watersheds, which include conservation tillage, riparian buffers, grass waterways, constructed wetlands, drop pipes, and tile drains. A more complete description of each watershed can be found in USDA-ARS (2005).

Table 1 CEAP benchmark watersheds.

Watershed	Managing Laboratory Location
South Fork of the Iowa River	Ames, IA
Walnut Creek	Ames, IA
Salt River/ Mark Twain Reservoir	Columbia, MO
Upper Washita River	El Reno, OK
Goodwin Creek	Oxford, MS
Little Topashaw Creek	Oxford, MS
Beasley Lake	Oxford, MS
Leon River	Temple, TX
Little River	Tifton, GA
Town Brook/ Cannonsville Reservoir	University Park, PA
St. Joseph River	West Lafayette, IN
Upper Big Walnut Creek	Columbus, OH

Laboratory Methods: Gamma spectroscopy will be used to determine the activities of ^{7}Be and ^{210}Pb$_{xs}$ in the soil, bank, and suspended sediments samples, as well as the precipitation samples. Samples are to be counted in standardized geometries for at least 82,800 seconds on a High Purity Germanium (HPGe) gamma detector and then for an additional 300 seconds with a standardized sealed source to account for self-adsorption of the ^{210}Pb photon (Cutshall et al., 1983). The counting efficiencies for ^{210}Pb were established using two mixed radionuclide solutions; ^{7}Be efficiencies were interpolated from the resulting curves of the efficiencies of the radionuclides present in the mixed solutions (Bonniwell, 2001 and Wilson, 2003).

Gamma spectroscopy provides a simple and non-destructive means of analyzing the radioactivity of each sample. Preparation of all samples for radionuclide analysis is minimal. Soil and sediment samples will be dried and separated into sand, silt, and clay size fractions because radionuclide sorption processes and preferential erosion mechanisms favor fine particles. The dissolved radionuclides in collected rain samples will be precipitated on a $Fe(OH)_3$ floc. The extraction procedure for the dissolved phase is detailed in Wilson (2003).

One limitation to this method is the substantial analysis time (~1 day), which is due to the low activities associated with environmental samples. Sediment particles are tagged with only the natural delivery of ^{7}Be and ^{210}Pb$_{xs}$ from the atmosphere. The long analysis time constrains the number of collected samples. A gamma spectroscopy lab has been established at the National Sedimentation Laboratory (NSL) in Oxford, MS to facilitate the analysis of the required samples for this study.

Field Methods: Samples must first be collected from both the landscape and stream banks in each sampled watershed to determine the background activities of ^{7}Be and ^{210}Pb$_{xs}$ of the potential source areas. Radionuclide activities on the landscape and in stream banks must be determined shortly before each sampled runoff event to ensure a strong relationship with the sampled runoff event. To accommodate the difficulty to predict adequate runoff events, radionuclide profiles less than two months old will be used, provided additions from the atmosphere and losses due to decay are accounted properly.

Soil sampling will be restricted to agricultural fields and pasture lands currently in use. The majority of erosion from the landscape will occur in fields with little vegetative cover where the soil has recently been loosened by tillage. Erosion on the landscape removes a thin layer of surface soils; therefore, high resolution soil profiles with sampling intervals of 0.5 cm will be taken to a depth of 5 cm. The soil profiles will have large surface areas (~200 cm^{2}) to ensure enough sediment is collected for analysis. Samples for gamma spectroscopy analysis at the NSL must be between 1 and 15 grams of sediment. Spatial variability of radionuclide activities on the landscape may be significant due to site specific characteristics; however, the number of samples is limited due to the long counting time and the relatively short half-life of ^{7}Be. Five soil profiles will be collected within each watershed.

Deeper cores from stream banks are required because bank failure removes larger volumes of sediment. To determine average activities of the bank material, the cores neither require the fine sampling resolution nor the large surface area of the soil profiles. The total depth of the cores will be 1 m and the sampling interval will be approximately 30 cm. Five bank cores also will be collected within each watershed.

The transport of fine suspended sediment in streams occurs most prominently during runoff events. Thus, suspended sediment samples will be collected during runoff events at each CEAP watershed. Suspended sediment samples will be collected at a designated site downstream of the soil surface and bank samples.

ISCO pump samplers can be used to collect suspended sediment. Fine suspended sediments in Goodwin Creek are well mixed (Kuhnle et al., 2001); therefore, point samples should provide adequate representation of the fine sediment load. Sampling should be evenly spaced throughout the hydrograph. ^{7}Be and ^{210}Pb tend to have higher concentrations when stage is rising as opposed to times when stage is falling or steady and is related to the timing of delivery of major sources of sediment from the landscape (Brigham et al., 2001). Much of the sediment removed from stream banks occurs as sloughs and toppling failures of banks particularly at decreasing stages (Thorne, 1992).

Sampling during runoff events will include collection of the precipitation to the watershed, as well as the suspended sediment in the streams. The radioisotopes ^{7}Be and ^{210}Pb are delivered in the precipitation, which produces the runoff event. The high partition coefficients of the radionuclides ($K_d \sim 10^4$ to 10^6; Wilson, 2003) result in rapid and strong bonding to the soil surface. The resulting radionuclide profile can be represented with an exponential fit (Owens et al., 1996; Wallbrink and Murray, 1996; and Wilson et al., 2003). The exponential fit can be used to determine the average expected activities of the radionuclides eroded from the landscape surface.

RESULTS

Each source material must have a unique radionuclide signature relative to the other in order to quantify the relative proportions from the different source areas in the suspended sediment. The activities of ^{7}Be and ^{210}Pb of the surface soils will be significantly higher than corresponding activities of the bank sediments. The radionuclide signature of the suspended sediment will lie intermediate along a mixing line between the signatures of the two end-member sources of sediment. Figure 2 is a graph of activities of ^{7}Be and ^{210}Pb of suspended sediments collected at a cross section of Goodwin Creek, MS, a CEAP benchmark watershed, relative to the average activities of the respective landscape and bank source materials. These data support the basic premise of the proposal. The suspended sediment lie along a mixing line, represented by the solid black line, between the average radionuclide signatures of the surface soils and the bank material. The mixing model allows determination of the relative contribution of sediment sources to the sediment load. Further interpretation of these data is in a following paper.

CONCLUSION

This study details a novel use of the activities of ^{7}Be and ^{210}Pb$_{xs}$ to differentiate the relative contributions of surface soils eroded from the landscape and collapsed bank sediment to the suspended load of streams in agricultural watersheds during runoff events. The two source materials have distinct radionuclide signatures. The suspended load of the stream is a mixture of the two source materials and plot along a mixing line between the source activities. This study will be applied to several CEAP benchmark watersheds to provide validation for watershed assessment models that can be used to address benefits of conservation practices and other environmental issues in the major agricultural regions of the nation and for use in future national assessments.

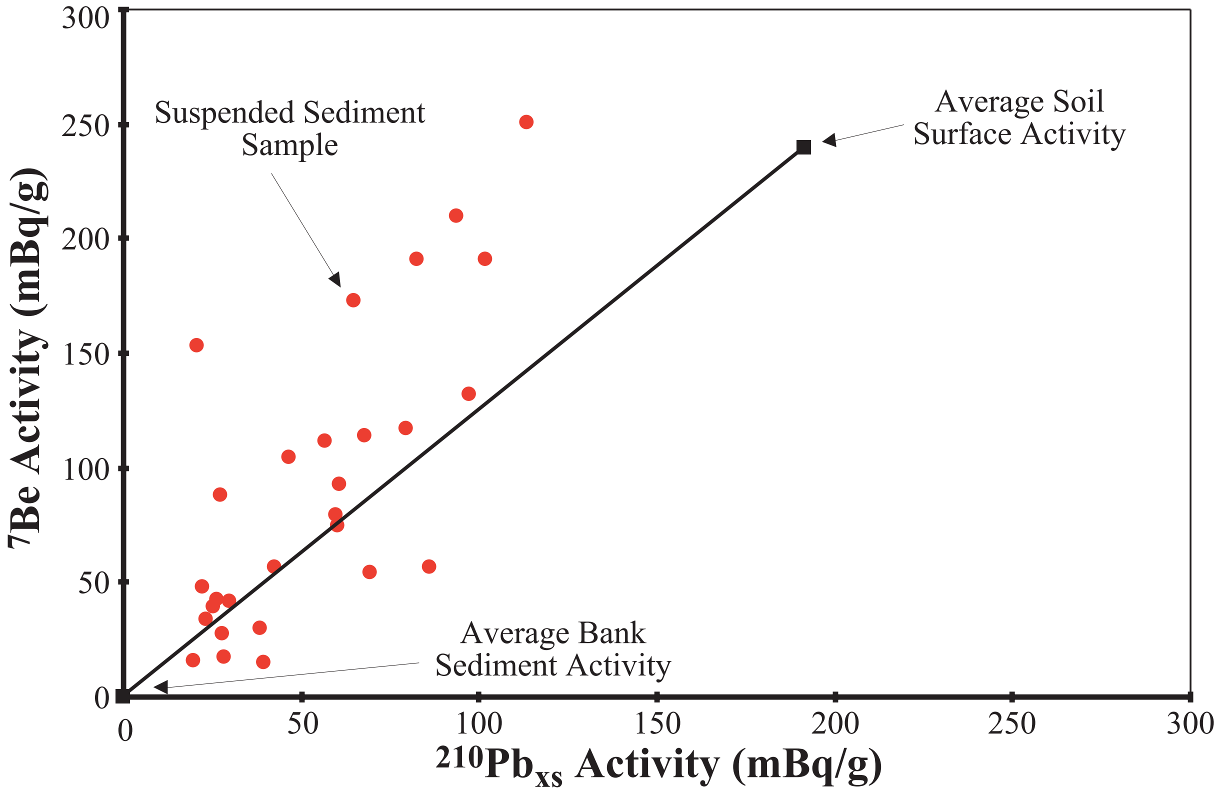

Figure 2 Activities of ^{7}Be and ^{210}Pb$_{xs}$ for soil, bank, and suspended sediment samples collected in association with a runoff event at Goodwin Creek, MS.

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