AEN-128

University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

Sediment Fingerprinting

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Sediment is one of the most common pollutants in waterbodies such as streams, rivers and lakes. Sources of sediment include upland areas, meaning lands above the floodplain, as well as the waterbodies themselves (Figure 1). Human activities that reduce or remove vegetation increase the amount of soil eroded. In the uplands, examples of sediment sources include tilled crop fields, grazed pastures, construction sites, and timber harvesting areas. Along water bodies, the beds and banks erode due to the force of moving water. Streambank erosion, for instance, contributes anywhere from 15 to 90% of the suspended sediment load in streams.

Figure 1. Sources of sediment in watersheds include (a) construction sites and (b) stream beds and banks.

(a) *Source: Matt Barton, Agricultural Communications*

(b) *Source: Carmen Agouridis*

Sediments in waterbodies cause a number of problems such as harming aquatic habitats, filling reservoirs, and worsening flooding. High amounts of sediment in the water inhibit the ability of fish and aquatic macroinvertebrates to move, breathe, hunt and reproduce (Figure 2). Accumulated sediments in reservoirs reduces their useful life and increases costs associated with maintenance. Streams experiencing such sediment buildup carry less water during storm events.

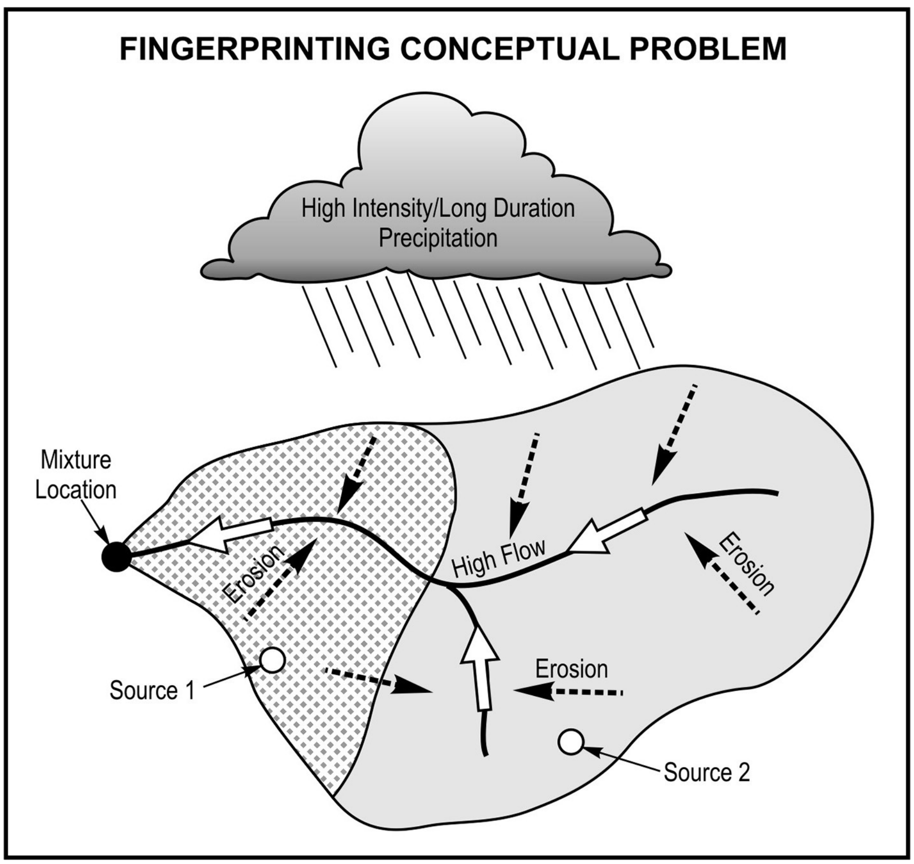
One way watershed managers can help protect waterbodies is through sediment budgeting. Sediment budgeting is a detailed accounting of the location, amount and method of sediment generation, transportation and deposition in a watershed. Locations where sediment is generated are called sources while places where sediment is mixed from various sources and/or deposited are called sinks. Once the source of sediment is known, watershed managers may implement best management practices for reducing sediment generation and transport.

Identifying the sediment sources and their relative contribution to waterbodies, however, is challenging. A number of factors such as vegetation type and density, soil type, topography, land use, and climate all influence sediment source, transport and deposition. One method of identifying sediment sources and the amount of sediment generated from the different sources is sediment fingerprinting.

Figure 2. Excessive amounts of sediment in streams cover gravels and cobbles on the bed meaning aquatic macroinvertebrates and fish have fewer living spaces.

Source: Carmen Agouridis

Figure 3. Sediment fingerprinting is used to identify the sources of sediments in a watershed.



Source: C.M. Davis and J.F. Fox, with permission from ASCE

Sediment fingerprinting is a relatively new method for identifying sediment sources in a watershed. With sediment fingerprinting, watershed managers use physical, chemical and/or biological tracers to distinguish between the types of sediment sources in a watershed and estimate how much sediment each source contributes to the stream (Figure 3). Sediment fingerprinting requires field, laboratory and modeling work.

Five Steps to Sediment Fingerprinting

Sediment fingerprinting involves five main steps: (1) classifying the sediment sources, (2) identifying unique tracers for each sediment source, (3) collecting and analyzing sediment samples from sources and sinks, (4) accounting for physical and biogeochemical changes in sediments and tracers, and (5) using an unmixing model to estimate the amount of sediment from each source (Table 1).

Table 1. Five main steps of sediment fingerprinting.

Step 1	Classify sediment sources
Step 2	Identify unique tracers for each sediment source
Step 3	Represent sediment sources and sinks
Step 4	Account for sediment and tracer fate
Step 5	Utilize an unmixing model for sediment source and fate

Step 1: Classify Sediment Sources

The first step in sediment fingerprinting involves identifying the potential sources of sediment in the watershed. Recall that potential sources of sediment include upland areas as well as the beds and banks of waterbodies. A number of techniques are available for identifying potential sediment sources. These methods include interviewing local Cooperative Extension Service and Natural Resources Conservation Service staff, discussing soil erosion "hot spots" with land owners, performing field inspections, viewing aerial images, or developing geographical information system models to identify areas within the watershed that have a higher potential for erosion.

Step 2: Identify Unique Tracers for Each Sediment Source

Like people, sediment sources have unique fingerprints. Sediment fingerprints rely on natural tracers that are characteristics of the sediment at its source. Examples of natural tracers that make up a sediment fingerprint are sediment color, shape, organic matter content, nitrogen isotope ratio, lead content, beryllium content, and microbial population such as *E.coli* content (Table 2). For a sediment fingerprint, the goal is to identify a unique combination of natural tracers that distinguish sediment sources from one another. This goal is accomplished using statistical analyses of tracer properties. Classification of sediment sources based on the type of erosion process occurring in the watershed can aid in identifying probable sediment fingerprints. If erosion is occurring from different land use sources, consider using the carbon and nitrogen isotope ratios of sediment. If erosion of surface soils is occurring, then consider using organic and radionuclide tracers. For stream bed and bank erosion, consider inorganic tracers that are related to the soil's geologic parent material. To date, the most successfully used tracers include iron (Fe), aluminum (Al), and caesium-137 (^{137}Cs), total organic carbon, total nitrogen, and isotopes of carbon and nitrogen.

Step 3: Represent Sediment Sources and Sinks

Sediment fingerprinting requires collection of sediment tracers from both sediment sources (i.e. areas of erosion) and sinks (i.e. areas of mixing and deposition). The method of sampling should match the erosion process. For example, in the case of surface erosion, one can collect grab samples of the top layer of soil. For subsurface erosion, such as when piping occurs, soil pits can aide in collection of sediments at lower depths. For stream bed and bank erosion, one can collect grab samples and/or shallow cores from the beds and banks. In urban areas, one can collect samples of sediments on roads. At the watershed outlet, where sediments from the various sources mix and/or are deposited, suspended sediment samples from streams are often collected. Techniques for sample collection include sediment traps, pump samplers, and depth-integrated samplers. Following sample collection, laboratory analyses are performed to determine the amount of tracer present.

Step 4: Account for Sediment and Tracer Fate

Ideally, the sediment fingerprint is conservative meaning that the natural tracers do not change during sediment transport to the sink location. In reality, tracers are often non-conservative. If tracers are non-conservative, the changes must be estimated and corrected for in the sediment fingerprinting analyses. The physical and biogeochemical characteristics of sediments and tracers can change during transport from the sediment source to the watershed outlet. Physical changes occur through processes such fractionzation, aggradation or disaggradation. Fractionization occurs when sediment particles naturally sort by weight. Heavier particles are harder to move while lighter ones are transported more easily. Because of fractionization, the size of sediment particles at the sampling location may be finer than the source. Aggradation is the joining of sediment particles (increase in size) while disaggradation is the breakdown of groups of sediment particles (decrease in size). Biogeochemical changes to tracers during transport include organic material decomposition and radionuclide decay (Figure 4). Karst topography can result

Figure 4. Tracers, such as the radionuclide caesium-137 (^{137}Cs) which has a half-life of 30.2 years, undergo decay.

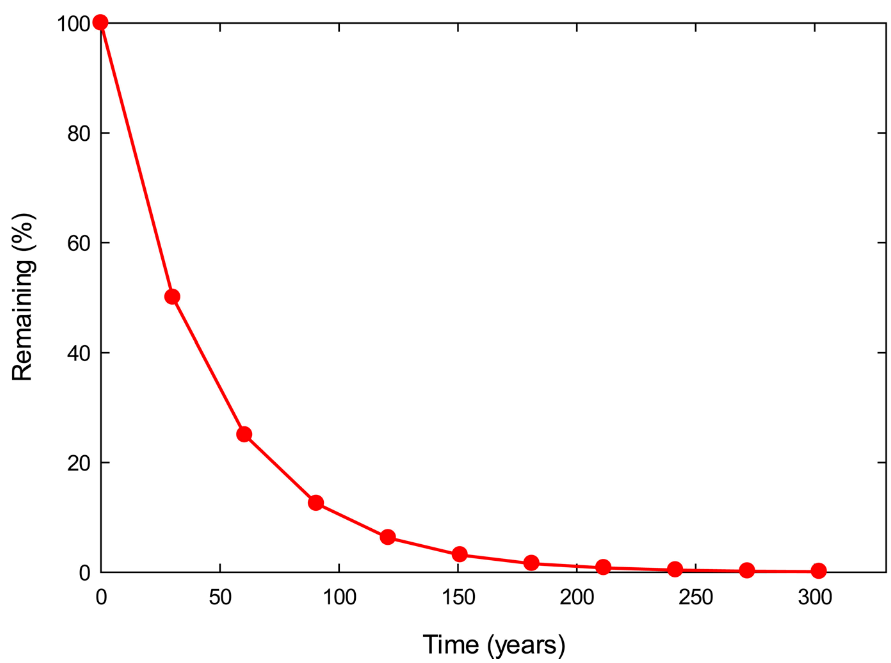


Table 2. Tracers are physical, chemical or biological in nature.

Characteristic		Example Tracers
Physical		Color, density, particle shape and size
Chemical	Organic	Total organic carbon, total organic nitrogen, carbon and nitrogen isotopes
	Inorganic	Aluminum (Al), copper (Cu), iron (Fe)
	Radionuclide	Caesium-137 (^{137}Cs), beryllium-7 (^{7}Be), lead-210 (^{210}Pb)
Biological		*E. coli*

in the loss of sediment and tracers from the surface water system to the ground water system. To date, scientists have developed correction factors to account for changes in sediments and tracers during transport.

Step 5: Utilize an Un-mixing Model for Sediment Source and Fate

Unmixing models are used to determine the contribution of sediment from each source. Unmixing models use mass balance equations, the mass of sediment sources and sinks, and the sediment fingerprints to estimate the fraction of sediment origination from each source. To date, scientists have developed unmixing models for single tracers (basic) as well as multiple tracers (multivariate).

How Sediment Fingerprinting Benefits Watershed Management

Since the mid-1970's, the field of sediment fingerprinting has grown considerably due to technological advances and the need to identify and understand sediment sources. Sediment fingerprinting remains a technique used mainly in research though the potential exists for its use in watershed management particularly with TMDLs. TMDLs or total maximum daily loads represent the maximum amount of a pollutant a waterbody can receive daily and still maintain an acceptable water quality level. Sediment fingerprinting can help watershed managers identify sources and the relative contributions of each source to a waterbody. Such information is helpful in the development and implementation of TMDLs.

One of the biggest challenges in using sediment fingerprinting is the required costs and labor. Because the process is watershed specific, the most appropriate tracers and potential sediment sources must be identified for each watershed. This work requires the collection and analysis of many samples. The process of sediment fingerprinting would also benefit from a greater level of standardization. While the main components are the same, small variations are present between users.

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Issued 2-2016