SOURCES OF FINE-GRAINED SUSPENDED SEDIMENT IN MILL STREAM BRANCH WATERSHED, CORSICA RIVER BASIN, A TRIBUTARY TO THE CHESAPEAKE BAY, MARYLAND, 2009

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INTRODUCTION

The Chesapeake Bay watershed, the largest estuary in the United States, was listed as an "impaired water body" in 2000 under the Clean Water Act, and excess sediment and nutrients were determined to be primary contributing factors for impairment (Phillips, 2002). Excess fine-grained sediment has reduced water clarity, which in turn has affected the Chesapeake Bay ecosystem (Phillips, 2002). In order to reduce sediment and nutrients transported to the Bay and as part of a targeted approach to reducing sediment input in the Corsica River watershed, the Maryland Department of Natural Resources (MDDNR) initiated a targeted watershed program directed at improving water-quality conditions in large watersheds draining to Chesapeake Bay. In 2006, the Corsica River became the first Targeted Watershed of the Chesapeake Bay in Maryland, where a comprehensive land-management program was designed to reduce sediment and nutrients and thus remove the entire Corsica River Basin from the State's impaired water bodies (303D) list (*http://www.dnr.state.md.us/watersheds/tw/corsica/index.html*; accessed November 17, 2009). In 2009, the U.S. Geological Survey (USGS) entered a partnership with MDDNR to identify the significant sources of fine-grained suspended sediment (<63-micron) in Mill Stream Branch, a tributary to the Corsica river and Chesapeake Bay with a 12.2 mi^2 (square mile) drainage basin (fig. 1). This report describes the results of this sediment-source study conducted from April 15, 2009 through September 20, 2009.

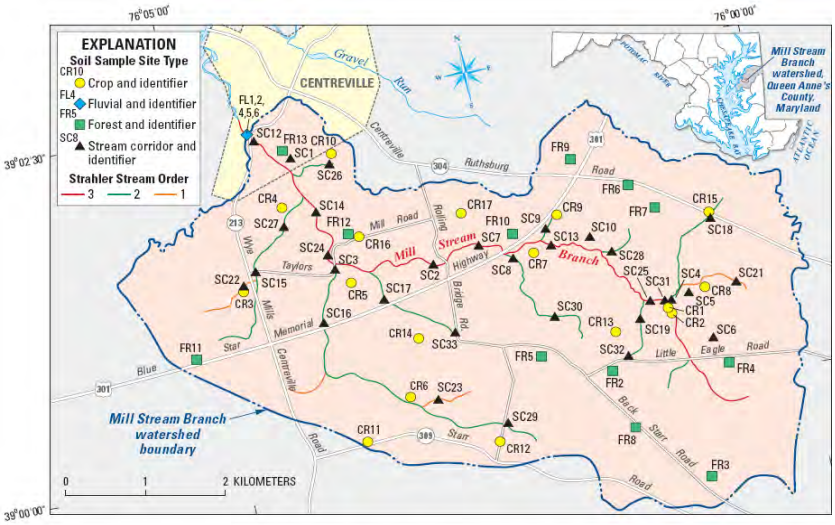

Figure 1. Location of Mill Stream Branch watershed above fluvial sampling location, Centreville, Maryland.

DESCRIPTION OF STUDY AREA

Mill Stream Branch is located on the Eastern Shore of Maryland in Queen Anne's County (fig. 1). The watershed is entirely within the Coastal Plain Physiographic Province and receives, on average, 52.5 inches of precipitation per year as measured at the National Weather Service rain gage at Royal Oak, MD, approximately 27 miles southeast of Centreville, MD. The topography of the area is characterized by gently rolling hills dissected by short, incised valleys (Overbeck and Slaughter, 1958). Over 90 percent of the soils in the study area are moderately well-drained clay-rich ultisols (Natural Resources Conservation Service, 2009).

The dominant land use (74 percent) in the Mill Stream Branch watershed is agriculture (pasture and cultivated crops such as corn, soy beans, and wheat) - (U.S. Department of Agriculture, 2002). Other land uses include forest (18 percent), wetlands (4 percent), and developed land (2 percent). Forests and wetland areas typically occur as riparian buffers, although there are some scattered forested plots throughout the watershed. Developed land is confined to the western part of the basin near Centreville, MD (U.S. Geological Survey, 2003).

Throughout the 19th and into the 20th centuries, the streams in these relatively incised valleys have provided energy through the creation of mill ponds. Specifically, the Mill Stream Branch Basin had at least two active mills, the oldest dating back to 1679 (Frederic Emory, Author of "History of Queen Anne's County", oral commun., April 20, 2009). Walter and Merritts (2008) in a study of historic mill ponds in Pennsylvania proposed that many streams in the Chesapeake Bay are actively eroding sediment that was deposited behind these mill dams.

APPROACH

In order to successfully implement strategies to control sediment mobilization, resource managers must be able to identify the significant sediment sources within a watershed. Traditional methods for identifying sediment sources typically require significant commitments of resources directed toward data collection and long-term monitoring. Walling (2005) points out that while traditional tools such as aerial photography, erosion pins, and erosion plots can document bank loss and sediment mobilization, these methods cannot determine how or if the material is delivered out of the stream system. As an alternative, sediment fingerprinting offers a direct method of quantifying suspended-sediment sources by identifying a minimal set of properties (or fingerprints) that uniquely define each source of sediment in the basin. Suspended sediment collected under a variety of flow conditions will exhibit a combination of the source material properties that, taken in aggregate, create a unique fingerprint that reflects the relative contribution of the sampled source materials to the sediment delivered by each sampled storm (Collins and Walling, 2002; Motha and others, 2003; Walling, 2005; Gellis and Landwehr, 2006).

A variety of tracers have been successfully been used to fingerprint sediment, including: mineralogy (Wall and Wilding, 1976); mineral magnetic properties (Klages and Hsieh, 1975); radionuclides (Nagle and others, 2007; and Whiting and others, 2005) trace elements (Devereux, 2006); and stable isotopes (Papanicolaou and others, 2003). The sediment sources fingerprinted in these studies included agriculture, forest, construction sites, urban sources, channel banks and beds, drainage ditches, and flood plains. By characterizing sources by a variety of tracer

properties and using a statistical mixing model to link the source fingerprints to those of suspended sediment, a quantifiable assessment of source contribution can be determined.

Sample Collection and Analysis Methods Five fluvial suspended-sediment samples were collected under a range of flows between April 15 and August 22, 2009, during storm events, from Mill Stream Branch using either a peristaltic pump or passive sampler. Three pumped samples were collected from the route 213 State Highway Bridge in Centreville, MD (fig. 1). The intake for the pump was placed mid-stream at 60 percent of the mean water depth at the time of sampling. Each sample consisted of approximately 450 L (liters) of water collected in multiple, clean plastic containers. Upon collection, the samples were immediately returned to the Baltimore laboratory of the USGS and processed using a Teflon-coated continuous-flow centrifuge to separate the suspended sediment from the water. The extracted sediment was dried at 50°C (degrees Celsius), and then disaggregated using a mortar and pestle. The material was then wet-sieved through a 63-micron nylon mesh and the silt and clay fraction was dried, weighed, and sent for chemical analysis to the USGS laboratory in Denver, Colorado.

Two suspended-sediment samples were collected using a passive sampler based on the design described by Phillips and others (2000). The passive sampler was located approximately 50 m (meters) upstream of the route 213 bridge and placed in the center of the channel at a depth estimated to be six tenths of the depth of the previous season's high flow as observed from well-defined high-water marks. The sampler was deployed during periods of low flow and retrieved immediately after a storm event. Upon retrieval, the contents of the sampler (approximately 8 L of sediment and water) were emptied into a clean plastic container and returned to the USGS Baltimore laboratory. Samples were allowed to settle for a minimum of 72 hours and then decanted to a volume less than 0.5 L. The resulting solution was wet-sieved and the fraction less than 63-microns was dried, weighed, and sent for tracer analysis (table 1).

Table 1 Sample types, bulk densities, D50 particle sizes, and locations for samples in Mill Stream Branch watershed, Queen Ann's County, Maryland, 2009.

[g/cm^3, grams per cubic centimeter; µm, microns; -- no data]

Site Name	Bulk density (g/cm^3)	D50 (µm)[1]	Latitude (decimal degrees)	Longitude (decimal degrees)	Site Name	Bulk density (g/cm^3)	D50 (µm)[1]	Latitude (decimal degrees)	Longitude (decimal degrees)
Crop					**Stream Corridor**				
CR1	1.62	13	39.009750	-76.017850	SC1	1.05	11	39.03639	-76.06694
CR2	--	16	39.009221	-76.017424	SC2	--	10	39.02060	-76.04993
CR3	1.82	14	39.021800	-76.078000	SC3	1.14	12	39.02222	-76.06417
CR4	2.1	11	39.030700	-76.069767	SC4	0.81	9	39.01083	-76.01806
CR5	1.45	11	39.020333	-76.062217	SC5	1.01	--	39.01127	-76.01430
CR6	1.56	15	39.005400	-76.057533	SC6	0.99	28	39.00523	-76.01240
CR7	1.46	9	39.019517	-76.035283	SC7	1.03	14	39.02172	-76.04287
CR8	1.39	12	39.011383	-76.011900	SC8	1.32	9	39.01937	-76.03838
CR9	1.63	14	39.023383	-76.030783	SC9	1.57	14	39.02203	-76.03250
CR10	1.42	11	39.035967	-76.060900	SC10	1.43	25	39.02005	-76.02668
CR11	1.32	9	39.001111	-76.065056	SC11	0.98	14	39.00389	-76.01611

CR12	1.12	11	38.998111	-76.046083	SC12	1.49	15	39.03917	-76.07167
CR13	1.21	7	39.008167	-76.026083	SC13	1.05	13	39.01973	-76.03269
CR14	1.5	13	39.012083	-76.054444	SC14	1.45	6	39.02944	-76.06528
CR15	1.46	13	39.020000	-76.008889	SC15	1.4	16	39.02389	-76.07556
CR16	1.69	8	39.025528	-76.059667	SC16	1.17	26	39.01611	-76.06722
CR17	1.07	12	39.025917	-76.044361	SC17	1.07	17	39.01750	-76.05806
Forest					SC18	1.42	17	39.01944	-76.00889
FR2	0.95	17	39.003667	-76.027750	SC19	0.85	12	39.00917	-76.02222
FR3	0.81	18	38.989083	-76.017000	SC20	1.62	13	39.00306	-76.01650
FR4	1.04	13	39.001861	-76.010917	SC21	1.37	18	39.01139	-76.00722
FR5	1.44	27	39.007028	-76.037500	SC22	1.32	22	39.02250	-76.07778
FR6	1.3	26	39.025139	-76.019556	SC23	1.34	18	39.00444	-76.05361
FR7	1.35	24	39.021944	-76.016556	SC24	1.27	9	39.02408	-76.06453
FR8	1.13	28	38.996556	-76.026278	SC25	1.67	11	39.01106	-76.02019
FR9	2.47	26	39.029528	-76.027000	SC26	1.34	23	39.03472	-76.06158
FR10	1.76	27	39.022250	-76.037639	SC27	1.57	13	39.02850	-76.07014
FR11	0.43	35	39.014778	-76.086889	SC28	1.5	--	39.01786	-76.02408
FR12	1.15	32	39.026056	-76.061028	SC29	1.39	16	39.00019	-76.04436
FR13	1.42	38	39.037417	-76.067806	SC30	1.7	7	39.01142	-76.03431
Fluvial					SC31	1.15	7	39.01081	-76.01722
FL1	--	13	39.040083	-76.072483	SC32	2.1	16	39.00508	-76.02511
FL2	--	16	39.040083	-76.072483	SC33	0.95	14	39.01194	-76.04903
FL4	--	20	39.040083	-76.072483					
FL5	--	14	39.040083	-76.072483					
FL6	--	15	39.040083	-76.072483					

[1.] Mean particle size of the less than 63 micron portion of sample

Table 2 Strahler stream order lengths and the number of samples collected by order in Mill Stream Branch, Queen Anne's County, Maryland, 2009.

Strahler stream order	Cumulative Length (meters)	Proportion of total stream length (percent)	Number of samples collected
3	32,548	35.3	11
2	49,191	53.4	16
1	10,399	11.3	6
TOTAL	**92,139**	**100.0**	**33**

Strategies for targeting sediment sources were based on findings from recent studies in other coastal plain settings (Gellis and Landwehr, 2006; Gellis and others, 2009). These sources included forest, cropland, streambanks, construction sites and drainage ditches. As no ditching or construction sites were identified in the basin, three possible sediment sources (cropland,

forests, and stream corridor) were targeted. Samples of potential source material representing crop (n=17 sites), forest (n=12 sites), and the stream corridor (n=33 sites) were collected from the surficial 0.5 cm (centimeter) of soil at each site using clean, all-plastic equipment (fig 1; table 1). Cropland sample sites were selected based on current land use and access to the site. Tillage at crop-sample sites included no-till, conventional till, and conservational till. Forest-sample sites were chosen based on access to the site. Both crop and forest samples were collected using a random walk approach within each site. This technique allows between about 20 and 50 samples, randomly collected over a field or forest tract, to be aggregated into a single, representative sample. Stream corridor samples were collected over a distance of two times the channel width upstream and downstream from the selected sampling point. Stream-corridor samples were collected from the bottom to the top of the exposed bank face. If banks on both sides of the stream were exposed, then both sides of the streambank were sampled. Sediment that appeared to have been deposited by a recent fluvial event was avoided. A geographic information system (GIS) was used to determine the length of stream orders in Mill Stream Branch, a third-order system. The number and location of the stream corridor samples for each stream order were collected approximately in proportion to the length of each stream order in the basin (fig 1; tables 1 and 2). All crop, forest, and stream corridor sample material were returned immediately after sampling to the USGS Baltimore laboratory and dried at 50°C for 48-72 hours or until dry. Once dry, the material was disaggregated using a mortar and pestle and wet-sieved through a 63-micron nylon mesh. The material passing through the mesh was again dried and sent to be analyzed for tracer properties at the USGS Denver laboratory.

Quality-control (QC) samples were collected throughout the sample collection effort to control sample bias. Six replicate source samples were collected – two from crop sites and four from stream-corridor sites to determine sampling error. A single sample of standard reference material 2709 was suspended in deionized water and passed through the continuous-flow centrifuge to assess sample preparation error (Paule and Mandel, 1982). In addition to these samples, three laboratory replicates of source samples (one forest and two stream corridor samples) were also used to determine analytical error.

Table 3 List of thirty-eight elemental metals used for fingerprint analysis denoted by Name (Symbol).

Silver (Ag)	Cadmium (Cd)	Potassium (K)	Phosphorus (P)	Selenium (Se)	Vanadium (V)
Aluminum (Al)	Cerium (Ce)	Lanthanum (La)	Lead (Pb)	Strontium (Sr)	Yttrium (Y)
Arsenic (As)	Cobalt (Co)	Lithium (Li)	Rubidum (Rb)	Sodium (Na)	Zinc (Zn)
Barium (Ba)	Chromium (Cr)	Magnesium (Mg)	Antimony (Sb)	Niobium (Nb)	
Beryllium (Be)	Cesium (Cs)	Manganese (Mn)	Gallium (Ga)	Titanium (Ti)	
Bismuth (Bi)	Copper (Cu)	Molybdenum (Mo)	Thorium (Th)	Thalium (Tl)	

Fluvial and upland source samples were sent to the USGS Geology Discipline research laboratory in Denver, CO, for analyses for 38 metals (table 3). All samples were analyzed using inductively coupled plasma combined with mass spectrometry after multi-acid decomposition (a mixture of hydrochloric, nitric, perchloric, and hydrofluoric acids). Specific details regarding this method can be found in (Taggart, 2002) or online at http://pubs.er.usgs.gov/usgspubs/ofr/ofr02223.

Statistical Methods To correctly determine the sources of suspended sediment for a given storm event, it is necessary to determine the set of tracers that most accurately discriminates

between the potential sediment source groups and enables the relative contribution of the individual sources to a specific suspended-sediment sample to be assessed. This is done by using a series of statistical and mathematical procedures that: 1) remove non-conservative elements, 2) remove elements that do not differentiate among/between sources, and 3) select the tracers that are most likely to correctly assign fluvial material to the possible source groups. Once this suite of tracers has been selected, an "unmixing" model is used to iteratively determine what proportion of each fluvial sample is ascribed to each source.

Thirty-eight elements were initially selected as potential tracers to fingerprint the sources of sediment (table 3). To remove non-conservative tracers, elements from all sampled fluvial events were bracketed with the equivalent elements from the potential source materials. Where the range of concentrations of an element associated with the fluvial samples was greater (within measurement error) than the overall range of concentrations of an element associated with the sediment sources, that element was removed from further consideration. Next, a Kruskal-Wallis H-test was performed on the remaining tracers to determine whether or not there was a significant difference in the ranked medians of each element by source group (Helsel and Hirsch, 1992). If there was a significant difference between at least one of the other group medians, the element was included as a potential tracer.

Collins and Walling (2002) and Collins and others (1997) have suggested that a composite of several tracers provides a greater ability to discriminate between sources than a single tracer. To create the optimal group of tracers, a stepwise discriminate function analysis (DFA) was used to select elements. This procedure assumes normality among the variables being analyzed; thus, all variables used in the DFA were tested for normality using the Shapiro-Wilk test (H_o = samples are random and come from a normal distribution). All variables that were not normally distributed at a 95-percent confidence interval were tested again for normality after transformation using either a log, power, or inverse function.

Next, a stepwise DFA was used to incrementally identify which tracers significantly contributed to correctly identifying the sediment sources and reject variables that did not contribute based on the minimization of the computed value of the variable Wilks' lambda (Collins and others, 1997). A lambda close to 1.0 indicates that the means of all tracers chosen are equal and cannot distinguish among groups. A lambda close to zero occurs when any two groups are well separated (within group variability is small compared to overall variability). Thus, the model selects a combination of tracers that provide optimal separation – no better separation can be achieved using fewer or more tracers. A significance value of 0.1 was used in the procedure. The ability of the DFA to correctly separate the sediment sources was evaluated at each step of the DFA by calculating the percent of samples correctly classified into their respective sources.

The final step in the procedure was to proportionally assign the contribution of the individual potential sources for each sediment sample. Gellis and others (2008) developed an unmixing model to determine the contribution of each source to the fluvial sample based on normalized scores (Snedecor and Cochran, 1980). The method compares the average absolute difference between the concentrations of each tracer in the fluvial sample to that associated with a hypothetical mixture composed of various proportions of the source materials. The best model is achieved when contributions from each source provide the closest match to the fluvial tracer

value, thus minimizing the variable E as shown in equation 1. The variable E is defined as the average absolute difference between each tracer value measured in the fluvial sample and the equivalent value that would occur in the proposed mixture, scaled by the relevant standard deviation for the mixture.

$$E = \left(\frac{1}{T}\right)\sum_{t=1}^{T}\frac{\left|v_t - \sum_{s=1}^{S} f_s A_{st}\right|}{\sqrt{\sum_{s=1}^{S} f_s^2\left(\frac{VAR_{st}}{n_s}\right)}} \tag{1}$$

where

t	= a specific element;
T	= the total number of elements;
v_t	= the value of the element t in the fluvial sample;
s	= a specific source area;
S	= the total number of source areas;
n_s	= the total number of samples for an individual source;
f_s	= the fraction of the contribution of source s to the entire sample, such that the sum of the S values of f_s is 1.0; and
A_{st} and VAR_{st}	= the estimated average and variance of the measured values of element t in source area s, respectively (Gellis and others, 2009).

RESULTS AND DISCUSSION

Five fluvial suspended-sediment samples were collected from five storms. Source samples collected throughout the watershed consisted of 17 samples from cropland, 12 samples from forests, and 33 samples from the stream corridor (fig 1).

Quality Control Sampling error, a calculation of the percent difference in replicate samples (data not presented here), for source samples ranged from 8.9 percent for cadmium to 1.89 percent for potassium with a median difference of 4.57 percent. Analytical error of source-sample concentrations (as determined from QC samples analyzed but not presented herein), ranged from 0.63 percent for strontium to 7.48 percent for cerium with a median difference of 2.35 percent. Bias (also calculated from QC samples not shown), introduced as a result of centrifuging fluvial samples, ranged from 78.2 percent for cadmium to zero percent for arsenic with a median difference of 5.8 percent.

The bulk densities of crop, forest, and stream corridor samples ranged, respectively, from 1.12 to 1.82 g/cm^3, 0.43 to 2.47 g/cm^3, and from 0.81 to 2.1 g/cm^3 Table 1). The median particle size of crop, forested, and stream-corridor samples ranged, respectively, from 7 to 16 µm (microns), 13 to 38 µm, and 6 to 28 µm.

Sediment-Source Fingerprinting Bracketing fluvial tracer concentrations with source-sample tracer concentrations showed that the range of concentrations of the fluvial samples were within the range of 24 tracers (including analytical error) of the source samples (elements listed in table 4). The fluvial concentrations were outside the range of 14 tracers (silver, barium, bismuth,

calcium, cadmium, copper, magnesium, manganese, sodium, nickel, phosphorus, antimony, strontium, and zinc) and these were removed from further consideration. A Kruskal-Wallis H-test of the remaining 24 tracers revealed that the ranked median concentrations of molybdenum and selenium did not effectively distinguish among source groups (table 4). Thus, these two additional tracers were also removed from further consideration.

Table 4 Median concentration values for source areas, Kruskall-Wallis h-test results, and probability values for 24 fingerprint properties that are bracketed by fluvial-sample concentrations from Mill Stream Branch, Queen Anne's County, Maryland, 2009.

[<, less than]

Fingerprint property	Median concentration for crop samples (parts per million)	Median concentration for forest samples (parts per million)	Median concentration for stream corridor samples (parts per million)	Kruskal-Wallis H-value[1] (unitless)	Probability value of Kruskal-Wallis test[2] (unitless)
Aluminum	53,500	36,400	60,300	23.04	<0.00001
Arsenic	5	2.95	6.2	19.68	0.0001
Beryllium	1.8	0.9	2.4	31.35	<0.00001
Cerium	82.2	41.9	84.7	25.7	<0.00001
Cobalt	6.8	3	11.7	32.2	<0.00001
Chromium	40.1	29	53	30.89	<0.00001
Cesium	2.3	1.8	3	26.48	<0.00001
Iron	18,400	8,545	21,800	26.85	<0.00001
Gallium	12.2	9.1	14.4	24.46	<0.00001
Potassium	15,500	11,550	14,200	24.84	<0.00001
Lanthanum	39	21	45.4	26.75	<0.00001
Lithium	23.1	14.3	29.4	32.21	<0.00001
Molybdenum	0.7	0.9	1	8.01	0.0182
Niobium	16	13.5	18	29.47	<0.00001
Lead	21.6	35.5	29.6	27.76	<0.00001
Rubidium	71.5	54.8	78.7	19.38	0.0001
Scandium	7.9	5.1	9.2	28.66	<0.00001
Selenium	1	1	1	3.91	0.1416
Thorium	9.37	5.98	9.04	27.72	<0.00001
Titanium	4,010	3,370	4,170	25.94	<0.00001
Thallium	0.54	0.45	0.67	29.39	<0.00001
Uranium	2.97	1.73	2.89	27.9	<0.00001
Vanadium	56.3	41.3	70.6	26.67	<0.00001
Yttrium	23.6	9.8	33.6	26.71	<0.00001

[1] H_0, null hypothesis, all medians come from the same distribution

[2] Reject the null hypothesis when the p-values is less than 0.01.

The remaining 22 tracers were tested for normality. Potassium, uranium, and lead were found to be non-normally distributed and were transformed. Values for potassium and uranium were squared, and a reciprocal function was used for lead. All 22 tracers were used in a stepwise DFA that minimized the variable lambda in order to identify the set of tracers that best separated the three sediment sources (table 5). Seven tracers (lithium, lead, potassium, titanium, uranium, chromium, and aluminum) were determined to best characterize samples by source type (table 5). Using these same data, the DFA was used to evaluate the performance of the model results by estimating the probabilities of misclassification of future results. This was done by using a discriminate function computed from each of the n-1 observations in the data set. The seven

Table 5 Selected results of a step-wise discriminant function analysis for identifying composite fingerprints for the Mill Stream Branch watershed, Queen Anne's County, Maryland, 2008.

Fingerprint Property	Wilks' lambda	Correctly classified source areas			Sum of correctly classified source samples	Sum of all source samples	Cumulative percent of source samples correctly classified
		Crop	Forest	Stream Corridor			
Lithium	0.43819	14	11	26	51	62	82.26
Lead	0.23183	15	10	25	50	62	80.65
Potassium	0.17003	16	10	25	51	62	82.26
Titanium	0.14	15	10	26	51	62	82.26
Uranium	0.11373	17	11	25	53	62	85.48
Chromium	0.09294	17	11	25	53	62	85.48
Aluminum	0.08404	17	11	26	54	62	87.1
	Number of samples collected from each source						

tracers together, were capable of correctly classifying over 87 percent of the source samples. Lithium alone, for example, was able to classify over 82 percent of the samples correctly (table 5).

The unmixing model was applied to the final seven tracer concentrations for the five fluvial storm samples (table 6) and tracer concentrations for the 62 source samples (by type; table 7).

Table 6. Hydrologic characteristics and final tracer concentrations for sampled storm events in Mill Stream Branch, Queen Anne's County, Maryland, 2009.

[m^3/s, cubic meters per second; Q, discharge; --, non-specific sample time and sample discharge; ppm, parts per million; P, passive; D pumped]

Sample Name	Sample collection method	Date[1]	Sample time[1]	Q[2] (m^3/s)	Peak Q[2] (m^3/s)	Time of peak Q	Al (ppm)	Cr (ppm)	K (ppm)	Li (ppm)	Pb (ppm)	Ti (ppm)	U (ppm)
F11	D	4/15	12:20	0.55	0.86	23:00	66,600	63.7	12,800	37.1	36.0	3,360	2.64
F12	D	5/7	8:00	0.69	0.89	16:00	63,400	58.4	14,600	35.0	34.0	3,180	2.71
F14	D	6/5	8:15	0.46	1.41	14:00	61,700	58.6	13,500	35.6	36.6	2,990	2.74
F15	P	8/2	--	--	0.80	--	62,200	60.1	13,800	35.4	40.0	4,400	3.17
F16	P	8/22	--	--	6.97	--	63,500	57.4	14,400	32.3	31.3	3,860	3.02

[1] Eastern Standard Time, 2009

[2] Data obtained from the Maryland Department of Natural Resources, November 22, 2009, Sean Smith, written commun., November, 2009.

The unmixing model was run on normally distributed concentrations of the seven elements by adjusting f_s, the fraction of source material in 1-percent steps.

The results of the sediment-source fingerprinting exercise indicated that 100 percent of the suspended sediment was derived from stream banks for each of the individual sediment samples collected from Mill Stream Branch over a range of discharges (0.80 to 6.97 m^3/s, or cubic meters

Table 7. Mean and variance of concentrations for tracers used in unmixing model for sediment source identification, Mill Stream Branch, Queen Anne's County, Maryland, 2009.

[ppm, parts per million; var, variance; n, number of samples]

		Al (ppm)		Cr (ppm)		K (ppm)		Li (ppm)		Pb (ppm)		Ti (ppm)		U (ppm)	
Source Type	n	Mean	Var	Mean	Var	Mean	Var	Mean	Var	Mean	Var	Mean	Var	Mean	Var
Crop	17	54,706	34,111,838	41.4	17.2	15,629	782,206	23.8	5.83	22.8	24.4	4,052	194,594	2.94	0.053
Forest	12	37,917	94,283,333	29.0	61.8	11,876	3,246,281	15.0	31.2	42.5	728	3,353	171,788	1.78	0.048
Stream Corridor	33	59,009	111,332,727	50.6	99.0	14,545	1,961,932	29.9	35.3	29.7	23.5	4,310	203,791	2.89	0.186

per second) and from five storm events which occurred in the spring and summer of 2009 (Table 8). Other sediment sources in the basin that were excluded by the model include contemporary cropland (nearly three-quarters of the land use) and forests (another 18 percent).

Table 8 Results for unmixing model showing contributions from three sources from five storm events, Mill Stream Branch, Queen Anne's County, Maryland, 2009.

[m^3/s, cubic meters per second]

Sample ID	Date	Peak discharge[1] (m^3/s)	% of source material			
			Crop	Forest	Stream corridor	Min E
Fl1	15-Apr-09	0.86	0	0	100	6.9086
Fl2	7-May-09	0.89	0	0	100	4.8941
Fl4	5-Jun-09	1.41	0	0	100	6.0901
Fl5	2-Aug-09	0.8	0	0	100	4.3274
Fl6	22-Aug-09	6.97	0	0	100	2.7523

[1] Data obtained from the Maryland Department of Natural Resources, November 22, 2009, Sean Smith, written commun., November, 2009.

These results contrast with the results found by Gellis and others (2009) for the Pocomoke River, a stream also draining the Delmarva Peninsula For the Pocomoke River Gellis and others (2009) found that cropland supplied 46 percent and stream banks 7 percent of the suspended-sediment for seven sampled events in 2001 and 2002. Thirty-five percent of the Pocomoke River watershed is was in cropland. The highly ditched Pocomoke River watershed provided a high sediment delivery from cropland to the stream network (Gellis and others, 2009). In Mill Stream Branch, low gradients and low stream power fail to provide a transport mechanism to move upland material toward streams. In addition, the stream network is a densely forested riparian corridor, which may also be limiting the delivery of cropland sediment to the channel.

In a study of stream morphology and the impact of historic milldams in Lancaster County, Pennsylvania, Walter and Merritts (2008) concluded that the thick deposits of fine-grained sediment along streambanks were a result of deposition behind mill dams. Subsequent failure of many of these dams has led to channel incision of these deposits and high rates of stream bank erosion. There is at least one, (probably two) historic mill present in Mill Stream Branch. Therefore, other factors such as bank height, bank angle, bank composition, and land-use history related to mill ponds may be providing conditions favorable to streambank erosion in Mill Stream Branch, but additional studies would be necessary to confirm this. The results of this study indicate that any management strategy aimed at reducing suspended-sediment loads in Mill Stream Branch should focus on the streambanks as the dominant sediment source.

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