FINAL REPORT

JAN 0 2 2003

1999 Project Abstract
For the period Ending June 30, 2002

TITLE: Identification of Sediment Sources in Agricultural Watersheds

Project Manager: Daniel Engstrom {Shawn Schottler}
Organization: St. Croix Watershed Research Station
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Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 1999, [Chap. 231], Sec.[16], Subd. [6b]

Appropriation Amount: $350,000

Overall Project Outcome and Results

Quantifying the contribution of overland sources versus streambank sources to riverine suspended sediment is fundamental to directing management efforts aimed at reducing sediment loads and achieving sustainable agriculture. A technique using radioisotopes and other geochemical tracers to fingerprint and quantify sources of sediment to rivers was successfully tested on two sub-basins in the Sand Creek watershed, Scott County, Minnesota. The technique employed in this study made several modifications to the methods presented by Walling and Woodward, 1992; Walling et. al, 1999; He and Owens, 1995. The underlying premise of the technique is that streambanks and soils with differing land use, mineralogy and exposure to atmospherically deposited radioisotopes and metals will have unique signatures of these tracers. Ten geochemical and isotopic tracers were identified that could statistically discriminate between sediments originating from erosion of streambanks versus cultivated fields. A source apportionment mixing model using the composite fingerprint of all tracers was developed to estimate the contribution from each erosion source. Erosion of streambanks accounted for greater than 70% of the total suspended sediment load measured during eight storm events in 2000 and 2001. For individual events, streambank erosion was estimated to contribute 45 – 95% of suspended sediment loading. Tile drainage networks and runoff from fields with perennial vegetation were determined to have negligible direct sediment inputs to the creeks in this study. However, flow from tile outfalls increases the flashy nature of the stream hydrograph and exacerbates streambank erosion.

Project Result Use and Dissemination

The results found in this study are almost certainly representative of larger watersheds, and it highlights the need to begin focusing management techniques and funding efforts on practices that can reduce erosion of streambanks. Findings from this study will be presented to state and local agencies concerned with reducing suspended sediment loads in Minnesota's rivers, and will also be presented internationally though journal publications and presentations at scientific meetings.

Date of Report: July 1, 2002

LCMR Final Work Program Report

I. PROJECT TITLE: Identification of Sediment Sources in Agricultural Watersheds

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Affiliation: St. Croix Watershed Research Station
Mailing Address: 16910 152nd St. N. Marine on St. Croix, MN 55047
Telephone Number: 651-433-5953 **E-Mail** schottler@smm.org **FAX:** 433-5924

Total Biennial Project :

$LCMR	350,000	**$Match:**	90,000 (cash)
-$LCMR Amt Spent:	350,000	**-Match Amount Spent**	90,000
=$LCMR Balance	0	**=$Match Balance**	0

A. Legal Citation: ML 1999, [Chap. 231], Sec.[16], Subd. [6b]

Identification of Sediment Sources in Agricultural Watersheds
$175,000 the first year and $175,000 the second year are from the trust fund to the Science Museum of Minnesota to quantify the contribution of streambank erosion versus overland erosion sources to riverine suspended sediment concentrations. This appropriation must be matched by at least $90,000 of nonstate money.

B. Status of Match Requirement: Metropolitan Council-Environmental Services (MCES) resolution on February 6, 1998 for $150,000.

II. & III. Final Project Summary

Quantifying the contribution of overland sources versus streambank sources to riverine suspended sediment is fundamental to directing management efforts aimed at reducing sediment loads and achieving sustainable agriculture. A technique using radioisotopes and other geochemical tracers to fingerprint and quantify sources of sediment to rivers was successfully tested on two sub-basins in the Sand Creek watershed, Scott County, Minnesota. The technique employed in this study made several modifications to the methods presented by Walling and Woodward, 1992; Walling et. al, 1999; He and Owens, 1995. The underlying premise of the technique is that streambanks and soils with differing land use, mineralogy and exposure to atmospherically deposited radioisotopes and metals will have unique signatures of these tracers. Ten geochemical and isotopic tracers were identified that could statistically discriminate between sediments originating from erosion of streambanks versus cultivated fields. A source apportionment mixing model using the composite fingerprint of all tracers was developed to estimate the contribution from each erosion source. Erosion of streambanks accounted for greater than 70% of the total suspended sediment load measured during eight storm events in 2000 and 2001. For individual events, streambank erosion was estimated to contribute 45 – 95% of suspended sediment loading. Tile drainage networks and runoff from fields with perennial vegetation were determined to have negligible direct sediment inputs to the creeks in this study. However, flow from tile outfalls increases the flashy nature of the stream hydrograph and exacerbates streambank erosion. The results found in this study are almost certainly representative of larger watersheds, and it highlights the need to begin focusing management techniques and funding efforts on practices that can reduce erosion of streambanks. Findings from this study will be presented to state and local agencies concerned with reducing suspended sediment loads in Minnesota's rivers, and will also be presented internationally through journal publications and presentations at scientific meetings.

IV. Outline of Project Results

See Section X.- Final Progress Work Summary for detailed results

Result 1: Development of Management Tool

Budget for Result 1:	**LCMR:**	**$190,000**	**Match:**	**$45,000** (cash)
	Balance:	**$ 0**	**Balance:**	**$ 0**

This project developed a technique to separate and quantify the sources contributing to suspended sediment in two small agricultural sub-basins of the Minnesota River, (Scott County MN). Specifically, this research utilized radioisotopes and other geochemical tracers as fingerprinting tools to determine the relative contribution of streambank erosion to total suspended sediment loads. The technique, which built upon similar studies applied to watersheds in Europe, provides a valuable tool, enabling watershed managers to quantify the importance of streambank erosion in larger watersheds and ultimately evaluate the effectiveness of soil management practices and streambank stabilization strategies on reducing sediment transport.

Outcomes from this project also include the development and continued operation of a gamma-radioisotope analytical facility, and a new sampler design for collecting sediments from runoff. Development of the radioisotope facility and the ability to efficiently use radioisotopes as tracers of erosion sources was essential to the success of this project. The radioisotope laboratory will continue to be used for "fingerprinting studies" and should prove integral in continuing to evaluate management practices designed to reduce streambank erosion. A second ancillary outcome from this project is the design of a new sampling device (MISS) that can directly capture freshly eroded sediment mobilized during a storm event. The sampler, which is constructed of PVC pipe and consists of a flow collector and settling tube/trap, is easily deployed at the edges of fields, tile outfalls, or mounted in the streams themselves to collect an integrated sediment sample during each storm event. Because the sampler collects sediment mobilized during a storm event, it is assumed to provide a representative sample of the sediment that is actually transported to the creeks; thus, permitting the use of additional tracers and reducing the need to normalize for particle size or organic fraction.

Objective 1: Design, Construct and Instrument Fingerprinting Lab

- A fully functional gamma-radioisotope analytical laboratory was constructed. The lab will continue to operate and conduct analysis on projects related to using gamma emitting radioisotopes as sediment tracers or sediment dating tools.

Objectives 2 & 3: Field Sampling

- A new sampling device (MISS) was developed for this project which allowed for the collection of mobilized sediment. The MISS samplers developed for this project are an efficient means for sampling both mobilized sediment from fields and suspended sediments in small creeks. Collection of mobilized sediment during events permits the use of ^{7}Be as a tracer, and minimizes the need to correct for organic carbon and particle size differences. MISS samplers could prove useful in range of research areas needing to passively collect eroding sediments.
- Over 100 field samples were collected during 2000 and 2001 and analyzed for a suite of radioisotope and geochemical tracers. Samples were collected from four potential erosion source environs: 66 samples from cultivated fields, and 15 samples from streambanks; negligible sediment was collected from either tile outfalls or runoff from fields of perennial vegetation. Thus, the latter erosion sources were treated as minor contributors to suspended

sediment loads. Eight storm events were sampled in West Ravens Creek, Ditch 10, and the confluence below the two creeks. Duplicate samples were collected for nearly all events.

Objectives 4 &5: Fingerprinting Mixing Model and Data Interpretation and Reporting.

- A suite 23 geochemical tracers were evaluated for their ability to discriminate between sediment eroded from streambanks versus cultivated fields. Ten tracers were identified that could statistically different between the two erosion sources.
- Mean concentrations (or activities) of each tracer were combined to generate a composite fingerprint from each source.
- A source apportionment mixing model, incorporating the composite fingerprints, was developed to quantify the contributions from field and streambank erosion to the suspended sediment load in each creek.
- Effectiveness of the mixing model was tested by comparing measured concentrations of each tracer in suspended sediment samples, to concentrations predicted by the model. Average relative percent difference between measured and predicted values were less than 20%, indicating that the model is a reliable tool for estimating contributions from different erosion sources.

Result 2: Demonstration of Fingerprinting Tool

Budget for Result 2:	**LCMR:**	**$160,000**	**Match:**	**$45,000** (cash)
	Balance:	**$0**	**Balance:**	**$0**

A source apportionment mixing model was developed and applied to the composite fingerprints defined in Result 1. The model was used to quantify the relative contribution of bank and field erosion to suspended sediment in two Sand Creek sub-basins; West Ravens Creek and Co. Ditch 10. Results from these two watersheds show that erosion of streambank contributes greater than 70% of the suspended sediment load. This observation has significant management implications, since most current BMP's are targeted at minimizing soil loss from fields. Flow in these creeks is characterized by sharply rising and falling hydrographs which is exacerbated by discharge from tile outfalls. This type of flow regime can be highly erosive and is certainly at the root of the streambank erosion problem. If the results found for West Ravens and Ditch 10 are representative of the larger watershed it highlights the need to begin focusing management techniques and funding on practices that can reduce erosion of streambanks.

Objective 1 and 2: Field Sampling and Sample Analysis.

- Sediment samples from each of the source environments were analyzed for a suite of particle bound radioisotopes and geochemical tracers to construct a composite fingerprint. All samples were freeze dried and sieved to separate silts and clays from courser material. Only the fraction of sediment <60 um was used for analysis. Because actual mobilized sediment was collected using the MISS samplers, it was not necessary to apply any organic carbon or particle size fraction normalization.
- Approximately 50 samples were analyzed for a suite of magnetic properties. Examination of these results suggest that none of the magnetic properties are useful as source fingerprints.

Objectives 3, & 4 Fingerprinting Model Application, Data Interpretation

- The source apportionment mixing model (fingerprinting model) was applied to eight hydrologic events during May to July (2000 and 2001) for Ravens Creek and Ditch 10.

- Results of the fingerprinting model show that for all storm events, on both creeks, erosion of streambanks contributes at least 50% of the total suspended sediment load. On a cumulative seasonal basis, erosion of streambanks is responsible for more than 70% of suspended sediment loading
- Tile drainage networks and fields with perennial vegetation contribute negligible sediment to West Ravens and Ditch 10. No appreciable sediment samples were collected in MISS samplers deployed at tile outfalls or from fields of perennial vegetation. The observation that runoff from perennial vegetation fields contributes little or no sediment to the creeks is not surprising, and supports the concept that perennial vegetation as buffer strips is an effective means for reducing soil loss. However, it was surprising that the tile outfalls produced negligible sediment loading to the creeks. It would be useful to determine if this observation is representative at larger spatial and temporal scales.
- A summary describing the fingerprinting technique and evaluating the erosion sources in the Ravens Creek watershed will be disseminated to state and federal agencies in Minnesota, including MCES, Dept. of Natural Resources, Univ. of Minnesota, and the Scott Co. Watershed District. Findings will also be presented at national scientific meetings.

V. Dissemination

Professional audiences: The results of the research will be published in a peer reviewed scientific journal. The journal *Catena* has published several other studies related to sediment fingerprinting and is an appropriate venue for these results. Techniques and results of this research will be presented at conferences within and outside the State of Minnesota.

Interested parties: A summary report, and a one page fact sheets, will be prepared outlining: 1) the fingerprinting method as a tool for identifying sources of suspended sediment, and 2) results quantifying the importance of streambank erosion in the Ravens Creeks watershed. These reports will be provided free of charge to interested parties, particularly watershed management organizations, local government officials and fish/wildlife managers who have a strong interest in watershed issues. The reports will summarize the likely importance of different erosion sources to suspended sediment in agricultural watersheds and provide guidelines on how to apply the fingerprinting technique to determine which land uses / landscapes are the most significant contributors to suspended sediment.

VI. Context

A. ***Significance:*** This research is driven by the need to achieve both environmental and economic viability in Minnesota's agricultural watersheds. Understanding and reducing soil erosion is a foundation of sustainable agriculture. Soil loss from fields and subsequent transport in streams and rivers poses a serious environmental and economic risk in Minnesota's agricultural watersheds. Erosion of topsoil causes not only the loss of a nearly irreplaceable asset, but also severe water quality problems that threaten aquatic health and degrade the recreational value of surface waters. Current strategies to reduce suspended sediment concentrations are focused on curtailing overland sources. However, in many watersheds erosion of channel banks may be a major source of suspended sediment. Until the contribution of stream bank erosion to suspended sediment is quantified, future management endeavors may be misdirected. This project provides a technique that assesses the relative contribution from streambanks to suspended sediment loads. Study results enhance the ability of watershed mangers to implement programs that improve both agricultural and environmental viability in the effort to protect Minnesota's surface-water resources for everyone.

B. ***Time:*** All project objectives were completed by June, 30 2002.

C. *Budget Context*. The St. Croix Watershed Research Station (SCWRS), a division of the Science Museum of Minnesota (SMM), is dedicated to conducting and facilitating science on a watershed scale throughout the St. Croix and Upper Mississippi River basins. Staff at the SCWRS are currently involved in a number of other studies investigating sources, transport, and environmental processing of sediment, nutrients, and pollutants in watersheds in the Midwest. A brief budget history of these related studies is outlined below.

Budget History for 1994-1998

1. LCMR Budget History:
   - 1997-1999: $500,000 Watershed Science: An Integrated Research & Education Program
   - 1997-1999: $370,000 Atmospheric and Nonpoint Pollution Trends in Minnesota Lakes (Minnesota Pollution Control Agency--lead agency)
   - 1995-1998: $275,000 Atmospheric Deposition of Mercury Across Minnesota (Minnesota Pollution Control Agency--lead agency)

2. Non-LCMR Budget History
   - 1995-1997: $150,000 Historic and Modern Accumulation of Phosphorus in Lake Pepin. Funded by: Metropolitan Council Environmental Services
   - 1998-1999: $ 25,070 Study of Iron and Phosphorus Sedimentation in Vadnais Lake. Funded by: St. Paul Water Utility
   - 1998-1999: $ 45,400 A Paleolimnological Investigation of Trophic Change in Lakes of the Carnelian-Marine Watershed District; Funded by: Carnelian-Marine Watershed District.

   Capital cost of SCWRS 6,200 ft^2 research facility, 1995: $984,000
   National Park Service grant for GIS station at SCWRS, 1996: $21,000
   National Science Foundation grant for analytical equipment for SCWRS, 1996: $107,000

Revised Budget Summary 6-30-02: (LCMR dollars only, for three year project) **1999 – 2002**

Personnel:	Director- Dr. Dan Engstrom 3% time	$ 6,635	
	Senior Scientist, Dr. Jim Almendinger, 4%	7,790	
(Includes 27.5%	Assoc. Scientist, Shawn Schottler 83% time	105,240	
for Fringe Benefits)	Lab Coordinator, Kelly Thommes 60% time	75,700	
	Lab Tech./Research Staff 65% time	~~69,635~~ 72,232	267,597
Sub-Total			~~265,000~~
Equipment:	Gamma Counter,	$45,234	
Sub -Total			45,234
Development:	Gamma-isotope (fingerprinting) lab facility,	$ 5,814	
Sub- Total			5,814
Acquisition:		$ 0	0
Other:	General Lab/Field Supplies	$~~14,112~~ 17,664	
	Contract analytical services	~~10,000~~ 9,403	
	Contract field observer	0	
	Field Travel/Expenses	~~3,340~~ 2,122	
	Professional Development/Training	~~4,500~~ 2,166	
	Contract GIS mapping of land use	~~2,000~~	
Sub -Total		~~33,952~~	31,355
Total			**350,000**

Revisions to the budget summary reflect several changes in the project. Because of the sampling techniques developed by this project we were able to save money is several areas, mainly the reduced need for field expenses, a field observer and GIS mapping. Travel expenses were also less than expected. The money saved in these areas was used to buy liquid nitrogen for the Gamma Lab. Money that was saved in contract analytical services was used to fund SCWRS laboratory personnel to conduct similar analysis—namely measurement of soil organic carbon.

This project also leverages $150,000 allocated by the Metropolitan Council Environmental Services division (through user fees) to research the significance of streambanks as a source of suspended sediment.

Breakdown of Match

$90,000 cash match

- Equipment-Gamma Counter
- Development of gamma-isotope (fingerprinting) lab. (Includes workstation, instrument shielding, labware)
- Lab Technician 30% time
- General Supplies

$60,000 in-kind match

- $60,000 field measurements (flow and sediment monitoring)

VII. COOPERATION

	% time on project (3 year avg.)	*$LCMR (TOTAL for 3 YEARS)*
Dan Engstrom, Ph.D. SCWRS Director	3%	6,635
Shawn Schottler, Ph.D. SCWRS Assoc. Scientist, Co-PI, Project Manager.	83%	105,240
Jim Almendinger, Ph.D. SCWRS Senior Scientist	4%	7,790
Kelly Thommes, SCWRS Lab Coordinator	60	75,700
Lab Technician, Research Staff SCWRS	66	72,232
Mike Meyer, Ph.D. & Steve Balogh, Ph.D. Metropolitan Council Environmental Services	10	in-kind
Peter Beckius, & William Peters Scott County Soil and Water Conservation District	5	in-kind

The revised Cooperation summary reflects several reallocations of personnel time. In the fall of 1999, Dr. Engstrom became the director of the SCWRS and was required to shift his work duties. Other SCWRS staff also had job reclassifications at this time. Various SCWRS staff have provided expertise to this project and their contributions are summarized. Personnel costs ($) shown reflect a three year total (not a fraction of annual salary). Percent time worked on the project is an estimated average over the duration of the project.

VIII. LOCATION:

Project results are applicable statewide. Research was conducted at the St. Croix Watershed Research Station, Marine on St. Croix, Minnesota. Field application was demonstrated in the Sand Creek watershed (and Ravens Creek sub-basins), Scott County, Minnesota.

IX. Reporting Requirements

Periodic workprogram progress reports were submitted, March 2000, November 2000, and December 2001. A final workprogram report was submitted December 30, 2002.

Attachment A. Deliverable Products and Related Budget

LCMR Project Biennial Budget	Result 1	Result 2		
	Development of Fingerprinting Technique $	Demonstration of Fingerprinting Tool $	Total Budgeted for Project $	Total Spent $
Wages, salaries & benefits:				
Engstrom-Director/Sr. Scientist	5,165	1,470	6,635	6,635
Almendinger Sr./Assoc. Scientist	7,790	0	7,790	7,790
Schottler- Asst./Assoc. Scientist	51,590	53,650	105,240	105,240
Thommes-Lab Coordinator	29,820	45,880	75,700	75,700
Research Staff- Lab Tech/Interns	34,635	37,597	69,635	72,232
Total	129,000	138,597	**265,000**	**267,597**
Space rental, maintenance & utilities	0	0		**0**
Printing and Advertising	0	0		**0**
Communications, telephone, mail	0	0		**0**
Contracts: Professional/Technical/Analytical	0	9,403	**12,000**	**9403**
Local automobile mileage paid	0	0		**0**
Other travel expenses in Minnesota	1,000	1,122	**3,340**	**2122**
Travel Outside Minnesota	0	2,166	**4,500**	**2166**
Office Supplies	0	0		**0**
Other Supplies (lab)	9,000	8,664	**14,112**	**17,664**
Tools/Equipment	0	0		**0**
Office Equipment & Computers	0	0		**0**
Other Capital Equipment (Gamma Counter and associated fingerprinting facility)	51,048	0	**51,048**	**51,048**
Other direct operating costs	0	0		**0**
Land Acquisition	0	0		**0**
Land rights acquisition	0	0		**0**
Building improvement (fingerprinting facility)	0	0		**0**
Legal fees	0	0		**0**
Column Total	**190,048**	**159,952**	**350,000**	**350,000**

X. Final Workprogram Report
Identification of Sediment Sources in Agricultural Watersheds

I. Abstract

Quantifying the contribution of overland sources versus streambank sources to riverine suspended sediment is fundamental to directing management efforts aimed at reducing sediment loads and achieving sustainable agriculture. A technique using radioisotopes and other geochemical tracers to fingerprint and quantify sources of sediment to rivers was successfully tested on two sub-basins in the Sand Creek watershed, Scott County, Minnesota. The technique employed in this study made several modifications to the methods presented by Collins and Walling, 2002; Walling and Woodward, 1992; Walling et. al, 1999; He and Owens, 1995. The underlying premise of the technique is that streambanks and soils with differing land use, mineralogy and exposure to atmospherically deposited radioisotopes and metals will have unique signatures of these tracers. Ten geochemical and isotopic tracers were identified that could statistically discriminate between sediments originating from erosion of streambanks versus cultivated fields. A source apportionment mixing model using the composite fingerprint of all tracers was developed to estimate the contribution from each erosion source. Erosion of streambanks accounted for greater than 70% of the total suspended sediment load measured during eight storm events in 2000 and 2001. For individual events, streambank erosion was estimated to contribute 45 – 95% of suspended sediment loading. Tile drainage networks and runoff from fields with perennial vegetation were determined to have negligible direct sediment inputs to the creeks in this study. However, flow from tile outfalls increases the flashy nature of the stream hydrograph and exacerbates streambank erosion. If the results found for the creeks in this study are representative of the larger watershed, it highlights the need to begin focusing management techniques and funding on practices that can reduce erosion of streambanks.

II. Background and Hypothesis

<u>Importance and Problem:</u>

Soil loss from fields and subsequent transport in streams and rivers pose serious environmental and economic risks. Understanding and reducing soil erosion is a foundation of sustainable agriculture. High concentrations of suspended sediment in rivers can result from overland transport of sediment and/or channel erosion of streambanks. Separating the importance of overland erosion from channel-bank erosion has direct bearing on the direction of future management efforts. Current strategies to reduce suspended sediment concentrations are focused on curtailing overland sources; however, in many watersheds erosion of channel banks may be a major source of suspended sediment. Until the contribution of stream bank erosion to suspended sediment is quantified, future management endeavors may be misdirected. On a watershed scale, current measurement techniques provide only crude estimates of the relative importance of overland sources versus bank erosion. Furthermore, estimates of bank erosion are difficult to extrapolate from streambank field studies, and estimates based on sediment characteristics such as mineralogy have large uncertainties. Confirming the relative and absolute contributions of different sediment sources is paramount to efficiently allocating funding for land management/soil erosion programs.

This study developed a technique to separate and quantify the sources contributing to suspended sediment in two small agricultural sub-basins of the Minnesota River, (Scott County MN). Specifically, this research utilized radioisotopes and other geochemical tracers as fingerprinting tools to determine the relative contribution of bank erosion to total suspended sediment loads. Results from these two watersheds show that on a seasonal basis, erosion of streambank contributes greater than 70% of the suspended sediment load. This sediment fingerprinting technique should provide a valuable tool enabling researchers-managers to quantify the importance of streambank erosion in larger watersheds and ultimately evaluate the effectiveness of soil management practices and streambank stabilization strategies on reducing sediment transport.

Hypothesis:

Radioisotopes and Geochemical tracers as Sediment Source Fingerprints

Numerous studies have demonstrated the usefulness of radioisotopes to examine overland erosion processes (Collins et al., 2001; Walling et al., 1999; Wallbrink and Murray, 1993; Wallbrink and Murray, 1996; Olley et al., 1993; Walling et al., 1992). However, only recently have a limited number of studies used radioisotopes to distinguish between overland and streambank erosion. Walling and Woodward (1992) first presented the use of "radiometric fingerprints" as tracers of suspended sediment sources for two basins in the United Kingdom (UK). Subsequent studies in the same basin by He and Owens (1995) and Collins et al. (1997) successfully used radioisotopes and other geochemical tracers to separate streambanks from other erosion sources. To date, only limited similar studies have been conducted for watersheds in the United States (Brigham et al, 2001).

The underlying premise of this research is that streambanks and soils with differing land use and exposure to the atmosphere will have unique signatures of tracers such as radioisotopes, metals, and mineralogy. Comparing the tracer signature of soils from different sources with the signature of suspended sediment in rivers permits the contribution of each erosion source to be calculated. Because radio-isotopes such as ^{7}Be (half life = 0.14 yr), ^{210}Pb (half-life = 22.3 yr), and ^{137}Cs (half-life = 30.2 yr) are atmospherically deposited and have short to medium half-lives, they are particularly useful as tracers of sediment derived from channel-bank erosion versus recent overland erosion. For example, cultivated soils are exposed to the atmosphere and reflect recent isotopic inputs with little time for loss by decay. In contrast, streambank soils have minimal exposure to atmospheric inputs and have had much greater time for decay losses. Thus, suspended sediment derived by erosion of streambanks would have much lower concentrations of the above radioisotopes than suspended sediment derived by erosion of cultivated fields. Including a suite of diagnostic soil tracers, such as trace metals, makes the fingerprint of each source more clearly defined and the ability to separate sources more robust. Using a mixing model to apportion the concentration signatures of cultivated and streambank soils to the signature of the riverine suspended sediment, it is possible to determine the importance of each erosion source.

III. Methodology

The approach for this study involved two steps; fingerprinting a variety of potential sediment sources within each sub-basin, and then comparing the composite fingerprints to those of riverine suspended sediments. By comparing the signatures of sediment sources to the signature of suspended sediment through the use a mixing model, the contribution of each source was calculated. This method builds upon several recent studies (Collins and Walling, 2002; Collins et al., 1997; He and Owens 1995) that successfully used tracers to define a composite fingerprint for sediment sources and derive a multivariate sediment mixing model to quantify the contribution of each source to riverine suspended sediment concentrations.

Study Site

The Sand Creek watershed (area = 277 mi^2) in Scott County drains an intensive agricultural region where a variety of agricultural Best Management Practices (BMP) are being tested on a sub-watershed scale. Portions of Sand Creek have also been identified as having high streambank erosion potential. Streambank erosion rates of two to five thousand tons per year have been estimated for Sand Creek (Skone, 1990). Two sub-basins in the Sand Creek watershed, West Ravens Creek and County Ditch 10, were chosen as sites to develop and test the fingerprinting technique (Figure 1).

Discharge of West Ravens Creek and County Ditch 10 were monitored continuously for stream flow and routine samples are collected by the Metropolitan Council Environmental Services (MCES) for nutrients, suspended sediment, and BOD. Both West Ravens creek and Ditch 10 are tributaries that combine to form the main stem of Ravens Creek. A sampling site just below the confluence of the two tributaries was also sampled for suspended sediment. However, there were no flow measurements made at this site.

The Ravens Creek basin is characterized by undulating topography with loamy to clay soils. Most of the basin is underlain by relatively impermeable clay soils. Hence, most of the low areas in the basin are drained by sub-surface tile networks. Many of the low areas that collect water are drained into the tile network by use of vertical risers which have the potential to directly discharge sediment to the downstream ditches and tributaries. Most of the land in the watershed is actively cultivated to grow corn and soybeans, and a smaller amount for alfalfa. A limited amount to the land is enrolled in conservation programs and planted to perennial vegetation. Many stretches of Ditch 10 and West Ravens show obvious and recent

Sand Creek Watershed
Sampling Locations in Ravens Creek sub-basin

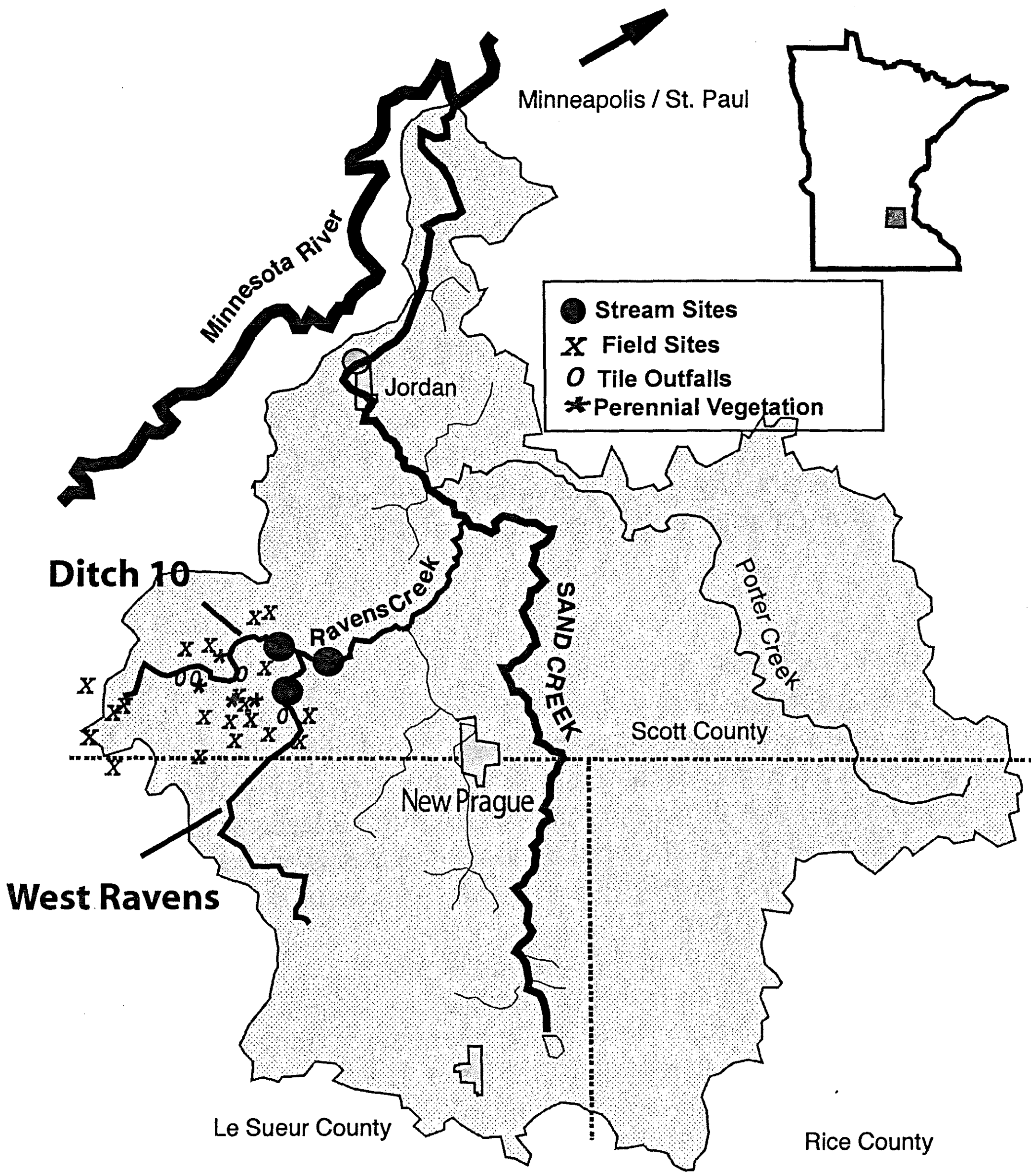

Figure 1. Sampling locations in the West Ravens and Ditch 10 sub-basins of Ravens creek. Four tile outfall sites, and four fields with perennial vegetation were sampled. Additional tile outfalls were grab sampled during an event in 2001. Thirty three locations were sampled for erosion from cultivated fields; during any event at least 15 samplers were deployed. Two suspended sediment samplers were installed at each of the stream sites. Bank sediment was grab sampled at 15 locations along West Ravens and Ditch 10.

streambank erosion. The stream is usually more than a meter below the floodplain and streambanks are often bare, exposed soil. These portions of West Ravens and Ditch 10 are low gradient streams, and much of the bank erosion is occurring by undercutting and scouring of the streambanks. This process appears to be common and continual as evidenced by living grass roots hanging down into streambank undercuts. Fewer locations with catastrophic bank collapse or sloughing were noted during this study.

Sediment Sampling:

Upland Sites:

Other "fingerprinting" studies generated source fingerprints by simply collecting surface soil samples from each of the potential erosion sources (Collins, et al., 2001; Walling et al., 1999, He and Owens, 1995). However, this approach may not represent the sediment that is actually delivered to a stream, and it is ineffective for tracers such as ^{7}Be that vary with each rain event. To compensate for these shortcomings, this project developed and utilized a new sampling device that would directly capture freshly eroded sediment mobilized during a storm event. The sampler is constructed of PVC pipe and consists of a flow collector and settling tube/trap (Figure 2). This Mobilized Integrating Sediment Sampler (MISS) was deployed at the edges of fields, tile outfalls, and also mounted in the streams themselves to collect an integrated sediment sample during each storm event. Because the sampler collects sediment mobilized during a storm event, it is assumed to provide a representative sample of the sediment that is actually transported to the creeks. MISS samplers were deployed at 33 upland locations throughout the Ditch 10 and West Ravens sub-basins (Figure 1). Four samplers were mounted to catch outfall from tile drainage networks; at least two of these tile drainage networks were connected to tile lines with vertical risers. Four samples were installed at the edges of fields growing perennial vegetation; three samplers were along edges of alfalfa fields, and one collected runoff from a field planted to native grasses. The remaining 25 samplers were installed at the edges of cultivated fields. At least 15 of the samplers were functioning during any particular storm event.

Samples were retrieved from collectors during storm events in May, June and early July of 2000 and 2001. Eight storm events during this period produced samples of sufficient mass to be analytically useful. Sample collection "success" varied depending on storm characteristics and from site to site. During some events most MISS samplers would collect sufficient sediment to provide a useable sample. During other events only 5-7 samplers would collect sufficient sediment. Not surprisingly, low intensity, low volume storm events produced the smallest samples. A total of 66 "useable" samples were collected from the edges of cultivated fields. Insignificant sample mass was collected from all tile outfalls and from fields of perennial vegetation. Thus, these latter two erosion sources are considered to be negligible contributors to riverine suspended sediment.

It would have been possible to collect more field samples and better characterize the source fingerprints; however, it would not have been possible to get all the samples analyzed. Be-7 has a half-life of 53 days, thus for its activity to remain above detection limit it must be analyzed within about 250 days of collection. Processed samples also needed to be sealed (ingrown) for 23 days to obtain measurements of unsupported ^{210}Pb. The laboratory could count one sample every two or three days, depending on activity. Blanks, standards, duplicates, and samples of suspended sediment and streambanks also needed to be analyzed. With these constraints it was only possible to do about 45 samples from cultivated fields per year.

Streambank Sites:

Grab samples of recently exposed soil along streambanks were collected to represent streambank erosion sources. The top 1 cm of soil was brushed away and a 10 cm core of soil was taken perpendicular to the bank face. Three cores from a site were taken and homogenized to create one sample. Seven sites along West Ravens and three sites along ditch 10 were sampled in 2000 and 2 additional sites along Ditch 10 were sampled in 2001.

Suspended Sediment Sampling:

Suspended sediment samples were collected at the two gauging stations on Ravens Creek and Ditch 10. MISS samplers were mounted on an adjustable pole (figure 1) near the center of each creek. Samplers were fixed about 5-10 cm above the water surface, and would collect continuously once the stream stage rose to this level during a hydrologic event. It was assumed that the samplers would collect an integrated sediment sample from a storm event, however, this assumption needs to be tested in further studies. Two samplers were deployed at each site. This provided for duplicate samples or back-up sampling if one sampler should be damaged. In general the deployment of the MISS into the streams was very successful and even during extreme flow events minimal damage to the samplers was experienced. It is noteworthy to mention that during several events the removable cup on the bottom of the MISS was overflowing with sediment! Total suspended solids samples were simultaneously collected by Metropolitan Council Environmental Services (MCES). These samples were processed by MCES and used to provide a flow-weighted measure of suspended sediment concentration and load. While these samples provide an excellent integrated sample of suspended sediment during a storm event, they were used by MCES for other analyses and were not of sufficient mass to be analyzed for tracer fingerprints.

Flow and Sediment Data:

Flow and water quality data were collected by MCES. Continuous stream stage was monitored using a pressure transducer coupled to a data collector. Stream stage was converted to discharge though a stage-discharge rating curve constructed for each stream site. Composited water samples were collected during hydrologic events using a Sigma Automated sampler. Water samples were processed for total suspended solids (TSS) and a suite of water quality parameters.

Mobilized Integrating Sediment Sampler (M.I.S.S.)

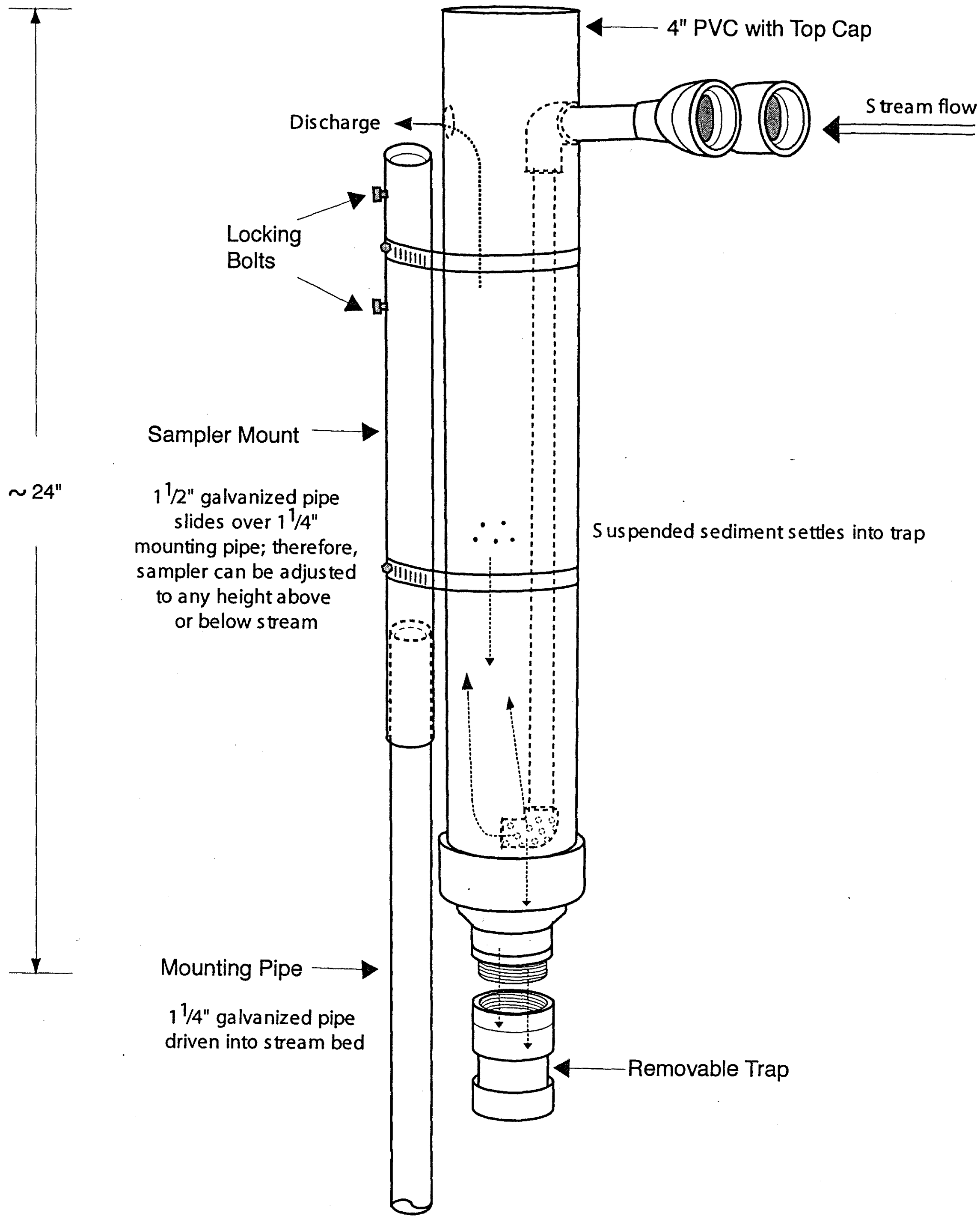

Figure 2. Sampler used to collect sediment from overland field erosion and suspended sediment at stream sites. The figure shows the arrangement used to deploy the sampler in stream sites. A very similar sampler was used at upland sites by burying an 8 inch casing in the ground and sliding the sampler into the casing. Intake holes are positioned at ground level to capture flowing runoff (and mobilized sediment) at field edges.

Analytical methods for tracers

Sediment samples from each of the source environments were analyzed for a suite of particle bound radioisotopes and geochemical tracers to construct a composite fingerprint. All samples were freeze dried and sieved to separate silt and clays from courser material. Only the fraction of sediment <60 um was used for analysis. Table 1 list the suite of tracers that were analyzed and evaluated as source discriminators.

Table 1. Potential sediment source discriminators.

Tracer	**Type**	**Description**
^{7}Be	Radioisotope	Naturally occurring, cosmogenic nuclide (t1/2 = 53 days) Atmospheric deposition.
^{137}Cs	Radioisotope	Artificial Nuclear byproduct, (t1/20 = 30.2 yr) Atmospheric fallout with time function
^{210}Pb (excess)	Radioisotope	Naturally occurring nuclide, (t1/2 = 22.3 yr), Atmospherically deposited.
^{232}Th	Radioisotope	Naturally occurring nuclide, (t1/2 =140 x10^{10} yr), Heterogeneous occurrence in lithosphere
Cu, Zn, Pb, Cr, Ni, Co,	Heavy Metals	Excess accumulation in surface soils from atmospheric pollution; also heterogeneous occurrence in lithosphere
χ_{lf}, ARM, IRM	Mineral Magnetics	Soil formation; atmospheric deposition of ferromagnetic materials.
Ca, Mg, Mn, Na, K, Fe	Major elements	Depletion in surface soils dependent from differential weathering, for K, potential enrichment on surface soils from synthetic fertilizers

Radioisotopes

The radioisotopes ^{7}Be, ^{137}Cs, and excess ^{210}Pb are deposited primarily through wet and dry precipitation and therefore are preferentially concentrated on surface soils. Thus, activities of the these radioisotopes are unique to different land uses and soil environments. For example, streambanks which have minimal exposure to the atmosphere are depleted of these isotopes relative to surface soils. Activities of radioisotopes were determined using high resolution gamma spectrometry, employing a low background germanium detector coupled to a multi-channel analysis system (Ortec-EG&G Instruments, Oak Ridge, TN). Freeze dried samples were gently packed into a 11 x 100 mm plastic tube to a height of 45 mm. Tubes were sealed with an epoxy resin to trap ^{222}Rn gas, allowing secular equilibrium to occur with daughter isotopes within a month. Samples in secular equilibrium can be analyzed for both total ^{210}Pb and mineralogical supported ^{210}Pb; the difference is deemed atmospherically deposited excess ^{210}Pb, or "unsupported"

^{210}Pb. Samples were counted for 48-72 hours. A standard efficiency curve (analogous to a calibration curve) was generated using a suite of isotopes with known activities over a range of emission energies. Standards of ^{210}Pb, ^{51}Cr, ^{7}Be, ^{109}Cd, ^{137}Cs, and ^{65}Zn were purchased from Isotope Products Laboratories (Burbank, CA), mixed into a cocktail and spiked into a sediment matrix. (Natural abundance of these isotopes in the matrix was effectively zero compared to the spiked activity, and was confirmed by running a matrix blank). This suite of radioisotopes provides an ideal efficiency curve for calibration since the three isotopes of interest in this study are included in the actual efficiency calibration. Detector blanks were run periodically during the study and all samples were blank corrected.

Heavy Metals, Mineral Magnetics and Major Elements

Trace metals such as Pb, Cr, and Zn are frequently enriched in surface soils by deposition of atmospheric pollutants and may therefore help to differentiate between recently eroded topsoil and older bank deposits. Mineral magnetic properties, such as χ_{lf} (low field susceptibility), ARM (anhysteritic remnant magnetism), and IRM (isothermal remnant magnetism), which are altered by pedogenic processes, have also proved useful in distinguishing topsoil from subsoil erosion (David et al., 1998; Banerjee et al., 1981). Major elements may be useful to distinguish between highly weathered surface soils from which carbonates and other soluble minerals have been leached and deeper horizons (bank slopes) only recently exposed to weathering.

Trace metals were extracted from sediment samples using a weak acid (0.5M HCL) and analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at the University of Minnesota, Geochemistry Laboratory. Major element chemistry was determined by lithium borate fusion (total digestion) and ICP-MS measurement. Mineral magnetic parameters were measured using magnetometers and susceptibility sensors by the Institute for Rock Magnetism at the University of Minnesota.

Source Discrimination-Source Fingerprinting:

The first step in developing a source apportionment model is to determine which of the radioisotope and geo-chemical tracers are successful in discriminating between different erosion sources. Since runoff from perennial vegetation fields and tile outfall yielded no sediment samples, tracers need only to discriminate between cultivated field and streambank sediment. Mean values of each tracer were statistically evaluated for their ability to differentiate between field and bank sediment using a Mann-Whitney U test. Results of the Mann-Whitney U test are shown in Table 2; tracers with probability values <0.01 were considered statistically significant in distinguishing between sediment eroded from fields versus streambanks. Three radioisotopes and seven trace metals were statistically significant as source discriminators. A sub-set of 30 samples from field sites and 10 streambank samples were analyzed for magnetic susceptibly. The range of values measured for bank samples completely overlapped with the values measured for field sites. Thus, the remaining samples were not tested and magnetic susceptibility was dropped as a source discriminator.

Table 2. Mann Whitney U-test probability values for individual tracers as discriminators between bank sediment and field sediment: n =15 for bank sediment samples, n= 66 for field samples. Even though Ba was significant in discriminating between bank and field sediment, it was not useful in the model because suspended sediment samples had greater concentrations than either source type. Pb-210 is excess or unsupported ^{210}Pb.

Tracer	Mann-Whitney U-test Probability value	Tracer	Mann-Whitney U-test Probability value	Tracer	Mann-Whitney U-test Probability value
Be-7	<0.0001	Si	0.058	Co	0.0003
Cs-137	.0001	P	0.8289	Ni	<0.0001
Pb-210	<0.0001	K	<0.0001	Se	0.1851
Na	0.1249	Ca	0.2594	Sr	0.8970
Mg	0.1510	Cr	<0.0001	Pb	<0.0001
Zn	0.0351	Cu	0.0057	Th-232	0.0253
Cd	0.4266	Ba	0.0004	U-238	<0.0001
Fe	0.6892	Mn	0.1024		

A summary of the range of concentrations measured for each of the tracers that were successful in differentiating between field and bank sediment is shown in Figure 3. For all tracers, concentrations (or activities) in bank sediments were less than concentrations in field sediments. As expected, concentrations in suspended sediments fall between the ranges of source concentrations. Except for Cu, the interquartile range of values observed in bank sediments is less variable than for field sediments. For several of the tracers (^{7}Be, ^{210}Pb, K, Pb, Ni, ^{238}U) there is distinct separation (no interquartile overlap) between the range of values measured between sources. This is characteristic of tracers that are robust in discriminating between bank and field sediments. Be-7 is a particularly diagnostic tracer. Activities measured in bank sediments were at or below detection limits. (The detection limit of 0.0005 was used for mathematical purposes). Therefore, ^{7}Be is indicative of sediment arising solely from upland sources. This is consistent with the fact that ^{7}Be is atmospherically deposited and has a short half-life.

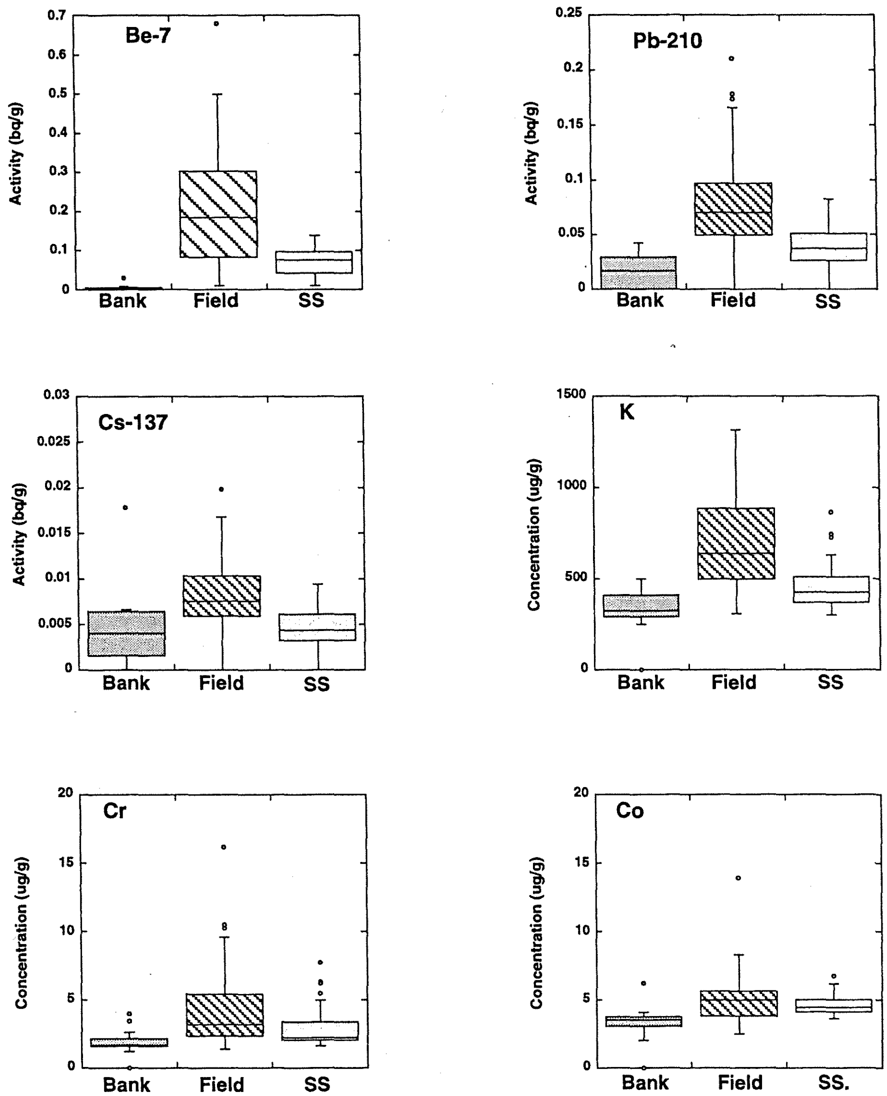

Figure 3a (and 3b below). Box plots showing the range of concentrations or activities measured for each tracer that was statistically significant in discriminating between streambank and cultivated field erosion sources (Note: ^{210}Pb is excess ^{210}Pb) Boxed values are the interquartile range of measurements, and encloses 50% of the data. Top and bottom of the box mark the limits of +/-25% of the variable population. Median values are displayed as a line in the box. Whiskers from the box are +/-1.5 times the interquartile range. ***Bank*** is the concentrations measured in streambanks, ***Field*** is the concentration for cultivated fields, and ***SS*** is the concentration measured in suspended sediments for both West Ravens and Ditch 10.

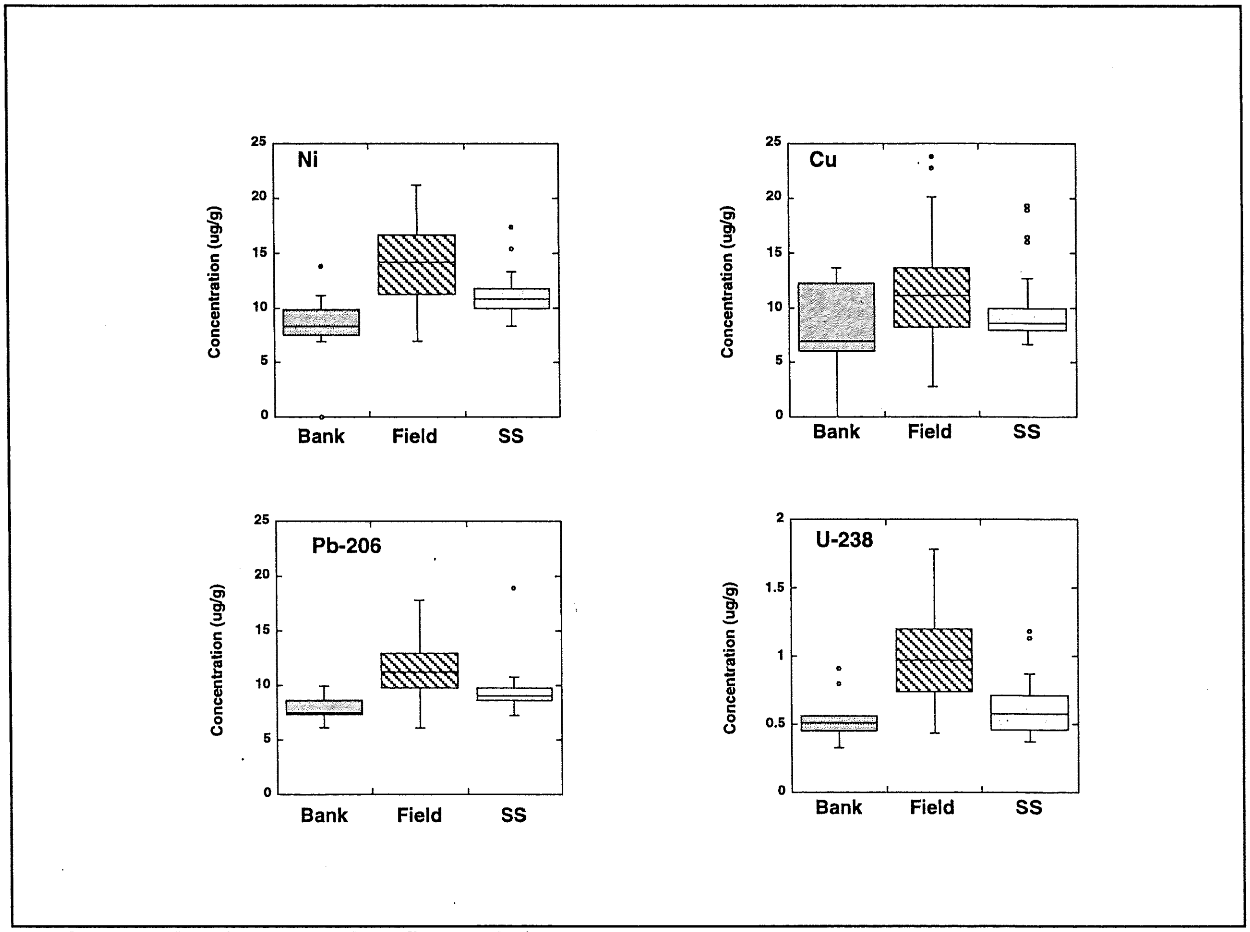

Figure 3b. (see caption figure 3a)

Source Apportionment Model

A source apportionment mixing model, similar to Collins (1997), was developed and applied to the tracer data to quantify the relative contribution of bank and field erosion to suspended sediment in each creek. In general the concentration of any tracer in a suspended sediment sample is equal to the mean concentration from a particular source times the relative contribution from that source, summed for all sources. Thus, the mixing model consists of a set of liner equations described as:

$$\sum_{i=1}^{n}\{(Css_i - pf(Cf_i) + pbs(Cbs_i))/(Cf_i - Cbs_i)\}^2 W_i \qquad \text{eqn 1}$$

Where Css_i is the concentration of tracer (i) in suspended sediment, Cbs_i is the mean concentration of tracer (i) in bank sediment samples, Cf_i is the mean concentration of tracer (i) in field samples, *pbs* is the percent contribution from bank sediment, *pf* is the percent contribution from field sediment, $Cf_i - Cbs_i$ normalizes tracers concentrations and W_i is a weighting factor. The mixing model must also satisfy the conditions;

$$pf_i + pbs_i = 1 \qquad \text{eqn 2.}$$

and

$$0 \leq pbs_i, pf_i \leq 1, \qquad \text{eqn 3.}$$

The set of equations described by eqn. 1 is over determined, thus the solution is defined by optimizing the values of *pf* and *pbs* to achieve the minimum value.

Table 3. Average source concentration used in the mixing model. Inverse of variance and the ratio of the field to bank mean concentrations were used to calculate a weighting factor. Be-7 was not detected in bank sediment samples; the detection limit for Be-7 was used for mathematical purposes.

Tracer	Avg. Concentration		Weighting Factor (W_i)
	Bank Sed. (Cbs_i)	Field Sediment (Cf_i)	
^{7}Be (bq/g)	0.0005	0.20676	74.6
^{210}Pb (bq/g)	0.0179	0.07861	10.9
^{137}Cs (bq/g)	0.00385	0.00879	1.77
K (mg/g)	362	770	1.49
Cr (mg/g)	2.06	4.3	2.48
Co (mg/g)	3.517	4.996	3.47
Ni (mg/g)	9.283	14.432	6.03
Cu (mg/g)	8.323	12.721	0.96
^{206}Pb (mg/g)	7.851	11.4185	8.41
U (mg.g)	0.5325	0.9602	8.21

Tracers that have less variability in their range of measured concentrations and have a greater absolute difference between mean values for bank and field sediment are more likely to provide reliable source discrimination. Specific weighting to account for these considerations was calculated as:

$$W_i = \left\{ {Cf_i}/{Cbs_i} \right\} x 1/s_i^2 \qquad \text{eqn 4.}$$

where si^2 is the normalize sample variance for each tracer. Sample variance was calculated using tracer concentrations of field samples only (normalized to mean) since these had a greater range and variability compared to bank sediment samples. Average concentrations and weighting factors applied to the model are shown in Table 3. Be-7 appropriately had the largest W_i since it is entirely associated with only one source. Interestingly, the model results run with and without the weighting factor are remarkably similar (see later discussion).

Other studies using radioisotopes and geochemical tracers have incorporated correction factors for organic carbon and grain size differences between source sediments and suspended sediments (Collins et al., 1997; Walling et al., 1999). In this study actual mobilized sediment was sampled directly during storm events, and only the size fraction less 60 um was used for analysis; thus, it should not be necessary to make any further size or organic carbon normalization.

IV. Results

The fingerprinting model was applied to 7 storm events (8 events for West Ravens) in the Ravens creek sub-basins. Five events in 2000, and two events in 2001 were modeled during May and June for each of the three creeks. An additional event in May of 2000 was modeled for West Ravens. Streamflow data during these events are shown in Figure 4.

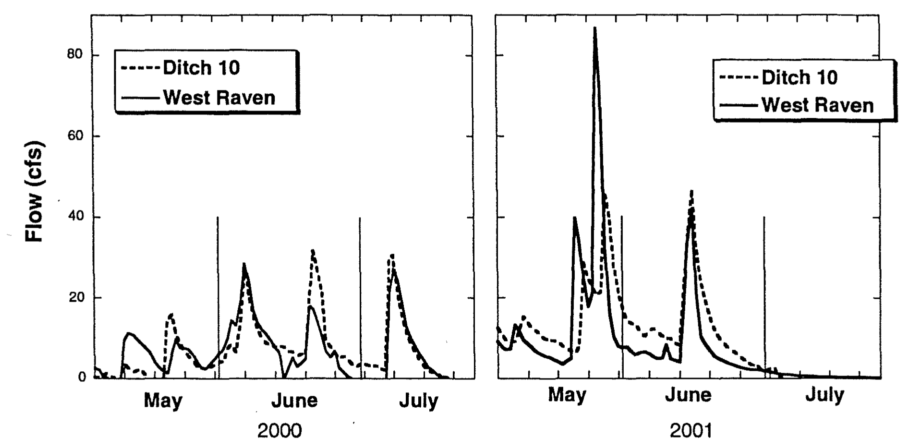

Figure 4. Discharge (ft^3/s) for Ditch 10 and West Ravens during May, June, and July, 2000 and 2001. Note that both creeks go to zero flow by mid-July in both years.

The fraction of suspended sediment contributed by erosion of streambanks during each of these events is present in Figure 5. For every event on West Ravens and Ditch 10, greater than 50% of the suspended sediment is predicted to arise from streambank sources. Similar results are observed for the site below the confluence of the two creeks, with the exception of events in 2001 where 25-45% of suspended sediment is predicted to have a streambank origin. For most events, two suspended sediment samples were collected at each site. The sample with the greatest collected mass was treated as the "main" sample and the sample with the smaller mass was treated as the duplicate. Figure 5 presents the results of both the main and duplicate samples. Agreement of modeling results between the two samples is remarkably similar for all events, with most duplicates agreeing within +/- 10% of fraction predicted for streambank contributions.

Table 4. Comparison of model results with and without using a weighting factor. Relative error describe the difference between predicted and measured concentrations of suspended sediment according to eqn 5.

		Fraction of SS from Bank Sediment		**Relative Error (%)**	
	Event	**w/out Wi**	**with Wi**	**w/out Wi**	**with Wi**
West Ravens	A	0.65	0.55	17.2	16.4
	B	0.78	0.65	15.1	13.8
	C	0.68	0.55	27.9	25.4
	D	1.00	0.88	13.1	24.2
	E	0.85	0.80	18.4	16.2
	F	0.90	0.88	9.1	9.5
	G	0.58	0.70	19.6	17.4
	H	0.53	0.58	19.1	18.2
Ditch 10	B	0.50	0.63	24.1	19.7
	C	0.78	0.50	25.8	26.3
	D	0.98	0.93	23.7	19.4
	E	0.95	0.83	25.7	20.6
	F	0.83	0.80	14.0	15.1
	G	0.53	0.53	18.4	18.4
	H	0.55	0.53	10.5	10.5
Confluence	B	0.55	0.58	14.5	14.1
	C	0.43	0.60	23.1	21.4
	D	0.83	0.78	14.6	14.3
	E	0.65	0.68	19.1	17.4
	F	0.58	0.63	14.5	12.4
	G	0.38	0.43	20.9	21.1
	H	0.14	0.25	31.6	36.3

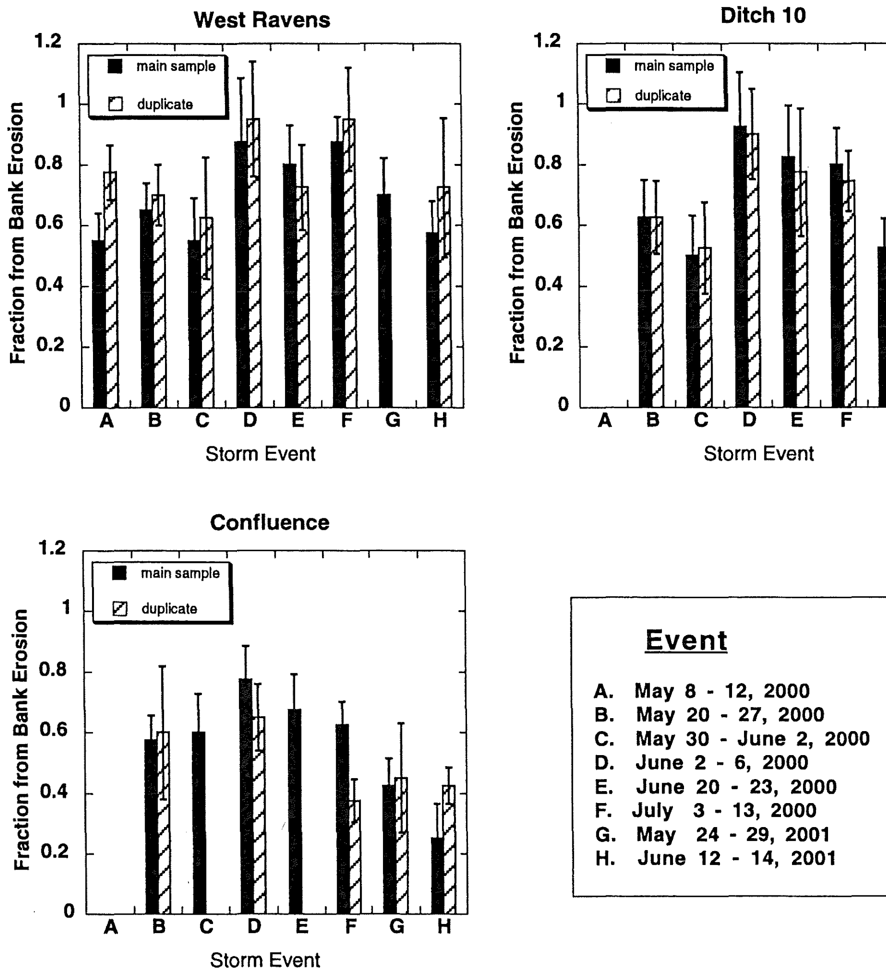

Figure 5. Fraction of suspended sediment concentrations contributed by streambank erosion at all three stream sampling sites. The main sample was simply defined as the sediment sample collected by the MISS with the greatest mass.

An estimate of the error associated with the model predictions was tested by comparing the actual concentration of each tracer in suspended sediment to the concentration predicted by the model using the estimated fraction contributed for each source. In other words, eqn. 1 was solved individually for *Css* of each tracer using the overall model predicted values for *pf* and *pbs*. This value of Css_i was then compared to the measured value of *Css* for each tracer, eqn 5.

$$\text{Relative Error} = \left[\sum_{i=1}^{n}\left\{\frac{(Cssm_i - Cssp_i)}{((Cssm_i - Cssp_i)/2)}\right\}\Big/ n\right] x100 \qquad \text{eqn 5.}$$

Where $Cssm_i$ is the measured suspended sediment concentration for each tracer and $Cssp_i$ is the concentration predicted using model estimates for *pf* and *pbs*. A similar assessment of error was defined by Collins, (1997). Error bars shown in Figure 4, and Table 5 are based on this calculation. Relative errors between Css_i *measured* and Css_i *predicted* ranged from 9 to 36% with an average of 19%, indicating that the model does an acceptable job of calculating *pf* and *pbs*.

An additional test examining model performance was done by comparing model results with and without applying the weighting factor, W_i. The weighting factor was defined to give additional significance to tracers that had low sample variance, and large separation between average field and bank sediment concentrations. This method heavily weights ^{7}Be and ^{210}Pb which have exclusively atmospheric inputs. Results with and without the weighting factor are shown in Table 4. Interestingly the result from the model are nearly independent of the weighting factor. This implies that in general, the solutions to the model based on individual tracers, such a ^{7}Be, are similar to the solution based on the composite fingerprint of all tracers, and that the variability introduced by an individual tracer is minimized by the strength of the model solution based on the composite fingerprint of all tracers. This observation supports the conclusions by Walling (2001) and others that sediment fingerprinting techniques are greatly improved by the use of multi-tracer composite fingerprints.

Table 6. Estimated suspended sediment loads originating from streambank and field sources during the major storm events of May to July of 2000 and 2001. Loading for the site below the confluence of these creeks could not be estimated because flow and TSS were not measured at this site.

	Loading from Streambank (kg)	Loading from Cultivated Fields (kg)	% of Total loading from Bank Erosion
West Ravens	68088	20683	77 %
Ditch 10	33340	13253	72 %

Sediment loads were calculated for the duration of each event by multiplying the cumulative flow volume for that event by the composited total suspended solids (TSS) concentration measured for that volume (data provided by MCES). By multiplying total sediment load by the fraction attributed to each erosion source, the amount of sediment load originating from streambank and cultivated field sources was estimated. Suspended sediment loads contributed by erosion of streambank and fields is shown in Figure 6. For all events, sediment loads contributed by erosion of streambanks is equal to, or much greater than the loading contributed by erosion of cultivated fields. For both creeks, during the runoff period of May and June, streambanks account for greater than 70% of total suspended sediment loading, (Table 6.)

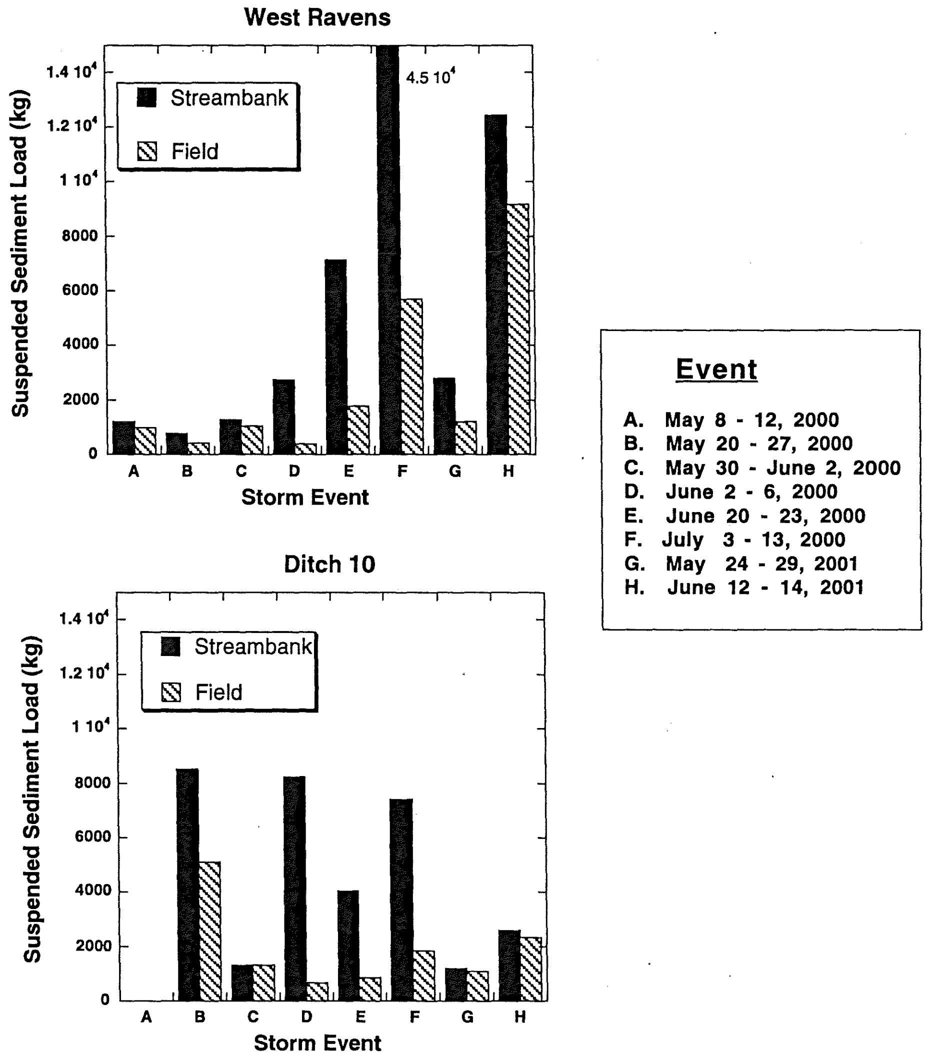

Figure 6. Contributions of streambanks and cultivated fields to suspended sediment loads on West Ravens and Ditch 10, 2000 and 2001.

Except for one major storm event in mid-May of 2001 that was missed due to an inability to access the stream sampling sites, the estimates in Table 6 represent the cumulative of storm events sampled during May to July; (i.e. sediments and loading during “base flow” were not measured). Since these events likely represent the majority of sediment loading during May and June, it is reasonable to assume that streambanks contribute greater than 70% of all sediment loading during these months. Flow in West Ravens and Ditch 10 went dry by mid-July in both years, effectively ending their sediment loading to the main stem of Ravens Creek. Similarly, it is likely that contributions to the main stem of Ravens Creek from cultivated fields throughout the watershed decrease during the summer as crops grow and reduce upland erosion. Therefore, it seems reasonable to conclude that except for the snow melt period, erosion of streambanks can be identified as the major, annual contributor to suspended sediment in the Ravens Creek watershed. Spring snow-melt for these creeks generally occurs by mid-April. This is a period of time when field are most vulnerable to erosion. It would be useful see how streambank and field contributions compare during the snow-melt hydrologic event.

Resuspension of previously deposited sediments in the creeks is a possible confounding factor to determining original erosion source. For tracers such as ^{7}Be that have a short half life, this is a real concern. However, the other tracers have no degradation or loss pathways that would change their signature while temporally stored as stream sediments. Long lived isotopes and trace metals should reflect their original source signature throughout downstream travel and resuspension. Bank sediments and very old stream bottom deposits may be indistinguishable in composite fingerprints; however, sediments that originated from field erosion should show a composite fingerprint of this source even during long term storage in the stream and subsequent resuspension. Thus, during any event, it is still possible to discriminate between field and bank (or old stream bottom) sources, even though the sediment may have originally entered the stream during a previous storm event. Even for ^{7}Be which has a half-life of 53 days, sediment eroded from cultivated fields should reflect at least a partial upland source for several months. During several events in the Ravens Creek sub basins, the ^{7}Be activity was only at detection limits, strongly indicating little or no recent inputs from fields. Additionally the strength of the mixing model is the use of composite fingerprints, which reduces the uncertainty in source apportionment introduced by variably in individual tracers; e.g. the potential depletion of ^{7}Be from older resuspended field sediments has little effect on model results which utilizes a composite of 9 additional tracers unaffected by storage/resuspension.

V. Summary and Discussion

1. Results of this study suggest that erosion of streambanks accounts for greater than 70% of total suspended loading during May to July for West Ravens and Ditch 10. This observation has significant management implications, since most current BMP's are targeted at minimizing soil loss from fields. Flow in these creeks is characterized by sharply rising and falling hydrographs. This type of flow regime can be highly erosive and is certainly at the root of the streambank erosion problem. If the results found for West Ravens and Ditch 10 are representative of the larger watershed, it highlights the need to begin focusing management techniques and funding on practices that can reduce erosion of streambanks.

2. Tile drainage networks and fields with perennial vegetation contribute negligible sediment to West Ravens and Ditch 10. No appreciable sediment samples were

collected in MISS samplers deployed at tile outfalls or in runoff from fields of perennial vegetation. The observation that runoff from perennial vegetation fields contribute little or no sediment to the creeks is not surprising, and supports the concept that perennial vegetation as buffer strips is an effective means for reducing soil loss. However, it was surprising that the tile outfalls produced negligible sediment loading to the creeks. At least two of the tile networks sampled were connected to vertical risers which could efficiently move water and sediment off the fields. In addition, during a large storm event in June of 2001, 12 additional tile outfalls were grab sampled. Sampling was conducted during the peak intensity of precipitation, and the outfalls were flowing vigorously. In all grab samples, total suspended solids concentration was less than 20 mg/l. While these samples were not applied to the fingerprinting model, they support the observation that tile outfalls in these sub-basins are a minimal direct contributor to suspended sediment loads. It would be useful to determine if this observation is representative at larger spatial and temporal scales.

While tile drainage networks may not be directly contributing to suspended sediment loads, they are certainly exacerbating the potential for erosion of streambanks. Tile networks are designed to quickly remove excess water from the fields and discharge it to ditches and creeks. This efficient removal of water contributes to the "flashy" nature of the stream hydrograph, and the erosivity of the discharge. Management practices designed to reduce suspended sediment loads must address the need to reduce the spike in the discharge hydrograph and the contribution and timing of tile flow to the overall stream discharge.

3. Use of multi-tracer composite fingerprints is a successful method to estimate sediment source contributions to streams. Ten geo-chemical and radioisotope tracers were identified which could significantly discriminate between bank and field sediment. Tracers were combined into a composite fingerprint and applied to a source apportionment mixing model. Measured concentrations of individual tracers in suspended sediment were compared to concentrations predicted using the composite fingerprint and source percentages predicted by the model. Average relative differences between measured and predicted values were less than 20%, suggesting that the fingerprinting technique is a reliable tool in predicting sources to suspended sediment.

4. The MISS samplers developed for this project are an efficient means for sampling both mobilized sediment from fields and suspended sediments in small creeks. Collection of mobilized sediment during events permits the use of ^{7}Be as a tracer, and minimizes the need to correct for organic carbon and particle size differences. MISS samplers could prove useful in a range of research areas needing to passively collect eroding sediments.

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