Sediment Fingerprinting Studies Identifying Watershed and Stream Corridor Sources of Sediment and Sediment-Bound Phosphorus

Overview by Faith Fitzpatrick, U.S. Geological Survey, Upper Midwest Water Science Center

Little Fork team: Anna Baker (co-PI), Shelby Sterner, Sam Soderman, Karen Gran, Andy Kasun, Mike Kennedy, Phil Norvitch, Jesse Anderson, Matt Gutzmann

Kinnickinnic River Team: Jim Blount, Leah Lenoch, Faith Fitzpatrick

East River Team: Heidi Broerman, Faith Fitzpatrick, Jim Blount, Tanja Williamson, Becky Kreiling

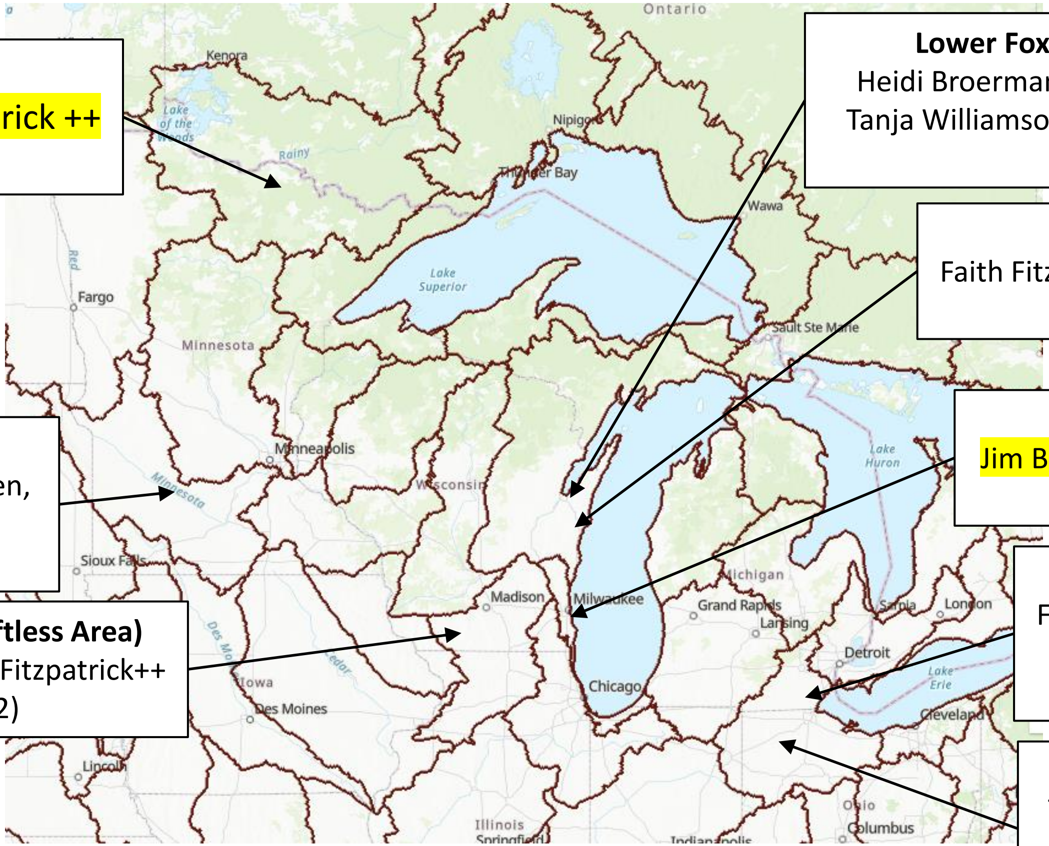
2025 Stormwater Workshop, virtual, 4/2/2025

Upper Midwest and Great Lakes Studies
Sediment & Sediment-P
Fingerprinting/Budget Studies

Little Fork, Rainy
Anna Baker, Faith Fitzpatrick ++
(2021-24)

Minnesota River trib
Tanja Williamson, Vicki Christensen, Faith Fitzpatrick++
(2011-2013)

Pleasant Valley (Driftless Area)
Jasmeet Lamba, Faith Fitzpatrick++
(2010-2012)



Lower Fox Tribs – East, Apple, Plum
Heidi Broerman, Faith Fitzpatrick, Jim Blount, Tanja Williamson, Becky Kreiling, Leah Kammel
(2016-25)

Sheboygan R Tribs
Faith Fitzpatrick, Jim Blount, Leah Kammel
(2011-13)

Kinnickinnic R
Jim Blount, Leah Kammel, Faith Fitzpatrick
(2020-21)

SE Michigan tribs –Lake Erie
Faith Fitzpatrick, Heidi Broerman, Anna Baker, Tanja Williamson, Becky Kreiling
(new start?)

Maumee R Tribs
Tanja Williamson, Faith Fitzpatrick, Becky Kreiling, Jim Blount
(~2018+)

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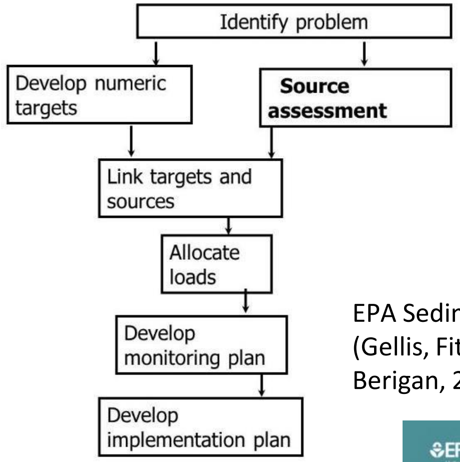
Sediment Fingerprinting and Budget Studies Objectives

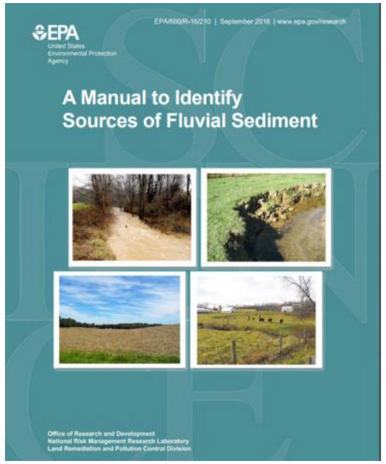
- Identify the main sources of suspended and streambed sediment and sediment-bound phosphorus from the watershed, including stream corridor sources and sinks.
- If available, fit results with watershed TMDL models and suspended sediment and phosphorus stream monitoring/loads data.
- Describe spatial and temporal variability in sources and sinks.
- Provide findings to land conservation and water resource managers for decision making.

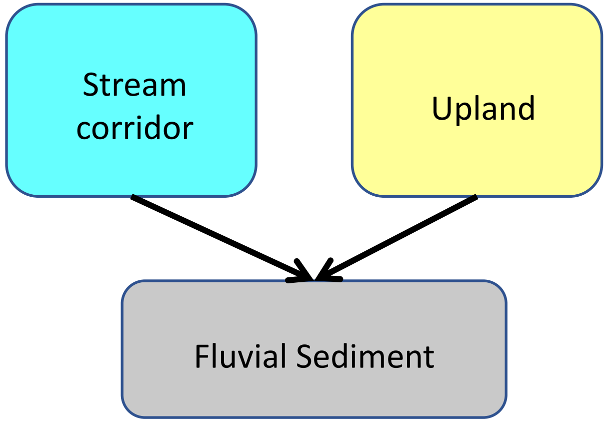
Sediment Fingerprinting Approach in the TMDL process

- Use established EPA sediment fingerprinting approach
- A sediment fingerprint is the combination of chemical tracers that best distinguish between the sediment sources
- Identify the relative proportion of each sediment source in a target sample, usually fine-grained, fluvial sediment

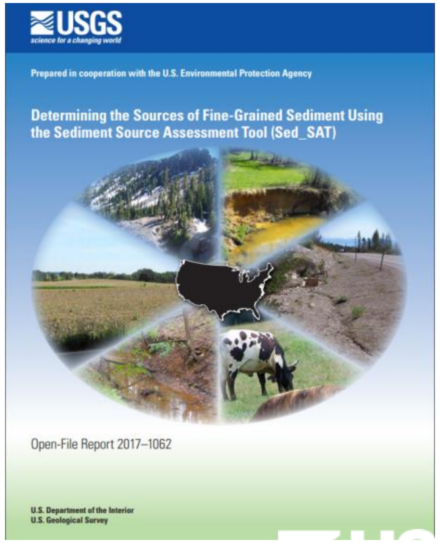


EPA Sediment Fingerprinting Manual (Gellis, Fitzpatrick and Schubauer-Berigan, 2016)





Sed fingerprinting tool (Gorman-Sanisaca, Gellis, and Lorenz, 2017)



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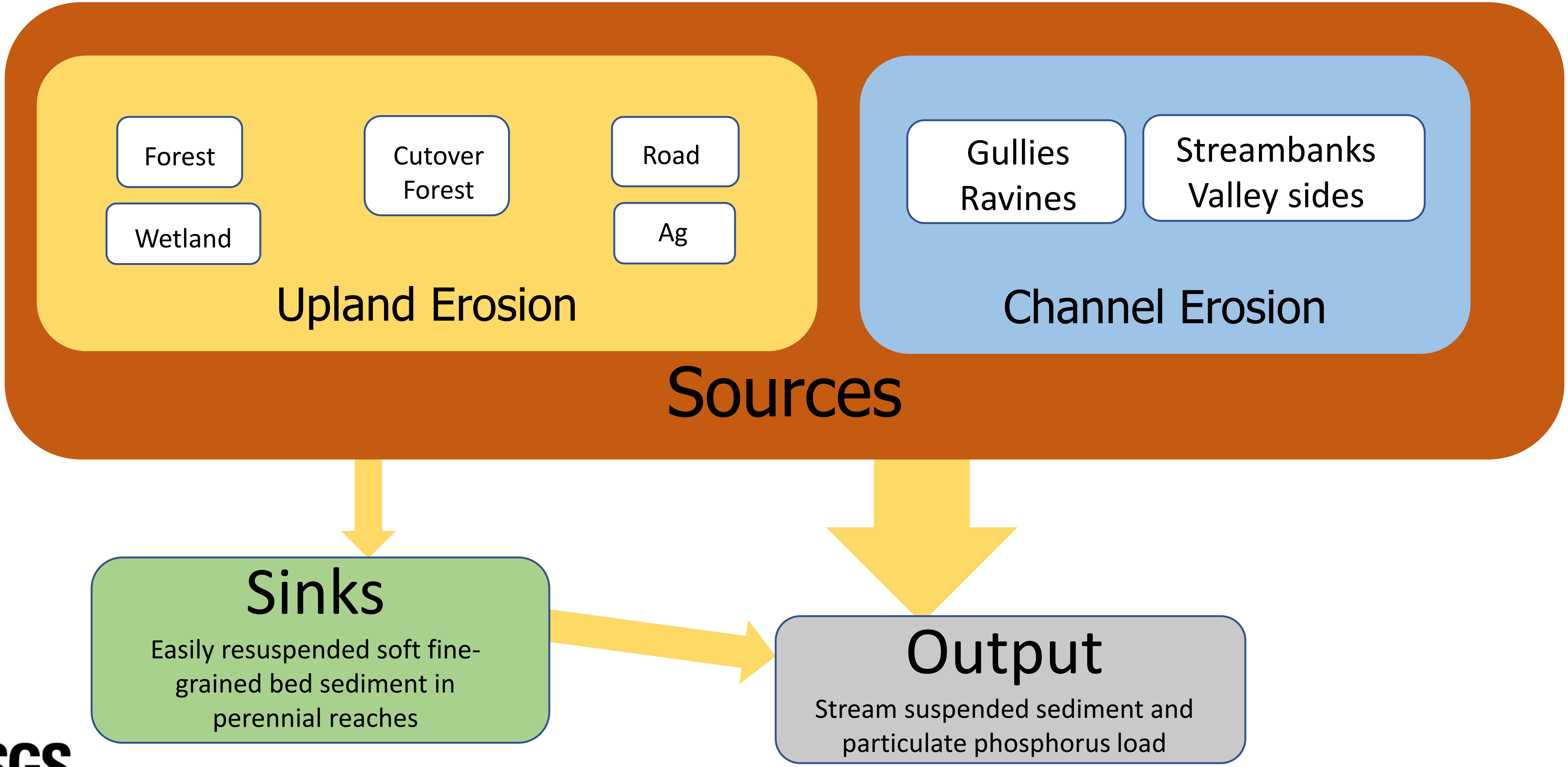
Example: Little Fork Sediment Sources, Sinks, and Output



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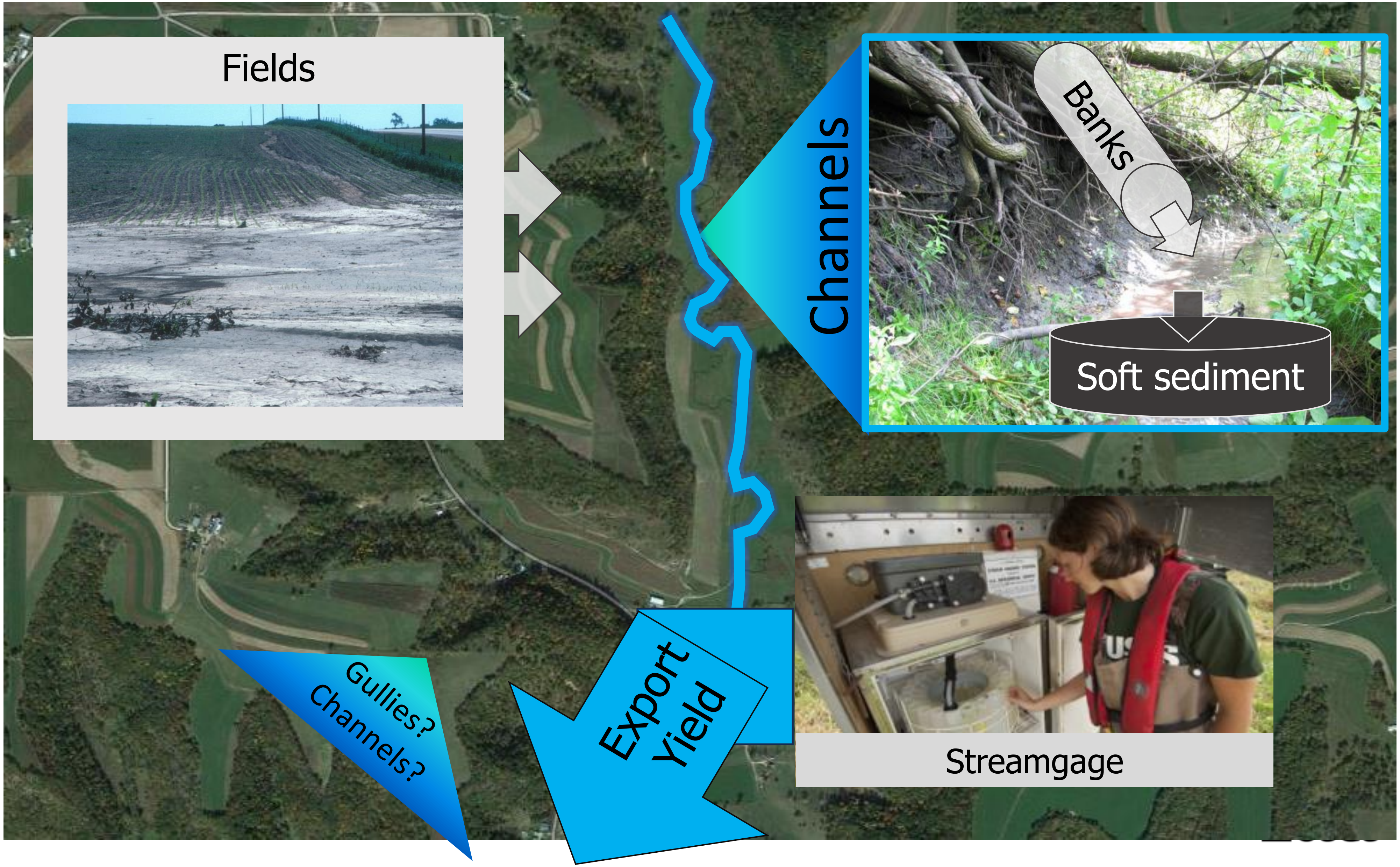
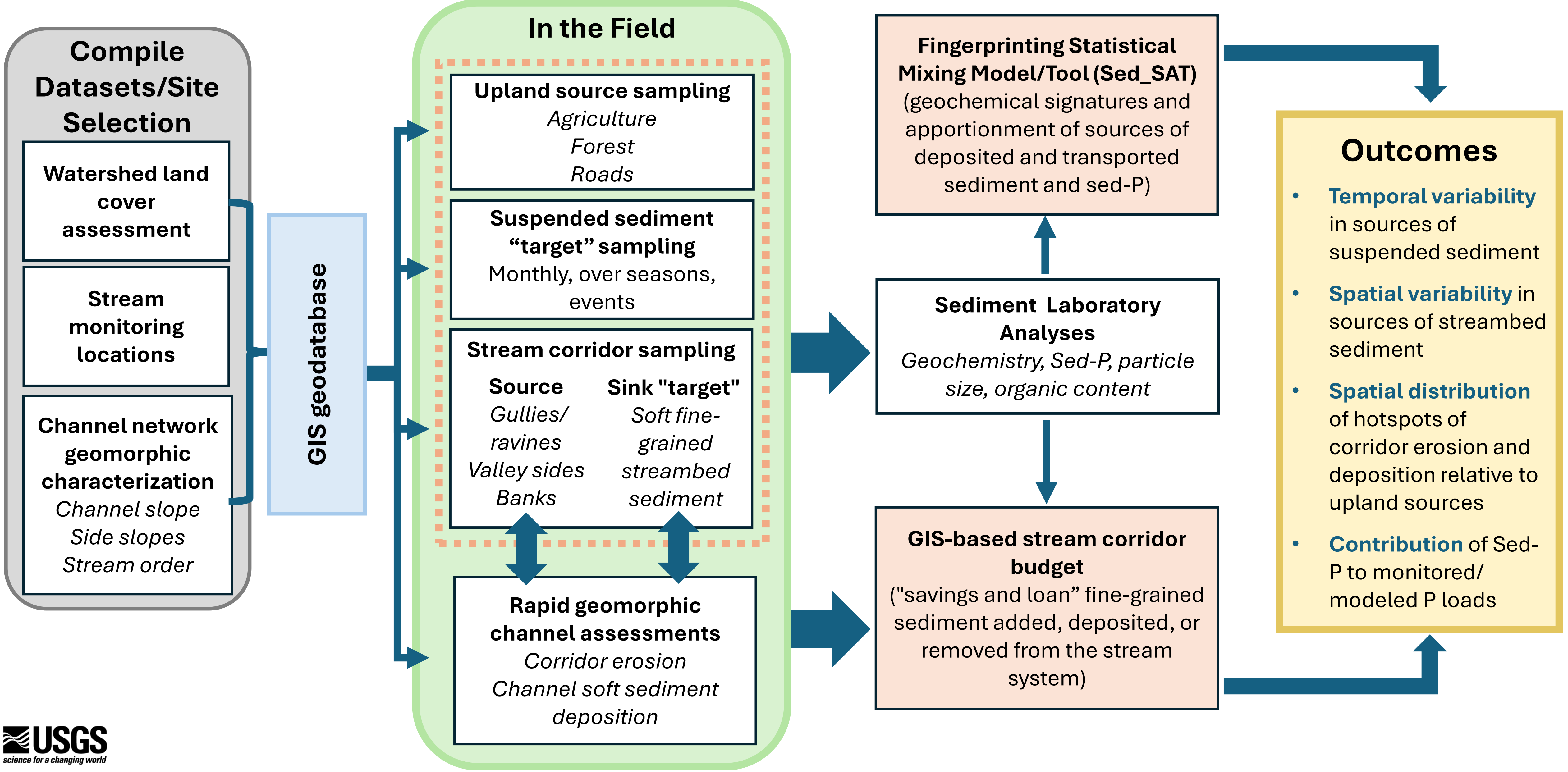
Sources and Sinks of Sediment and P



Sediment Fingerprinting and Budget Approach for Identifying Sources, Transport, and Sinks of Fine-Grained Stream Sediment and Sediment-bound Phosphorus (Sed-P) for TMDLs



Highlights from two recent studies

- Little Fork River, MN – large, forested, systematic accounting for gullies and ephemeral channels in the sediment budget

- Kinnickinnic River – small, urban, accounting for urban sources in the fingerprint

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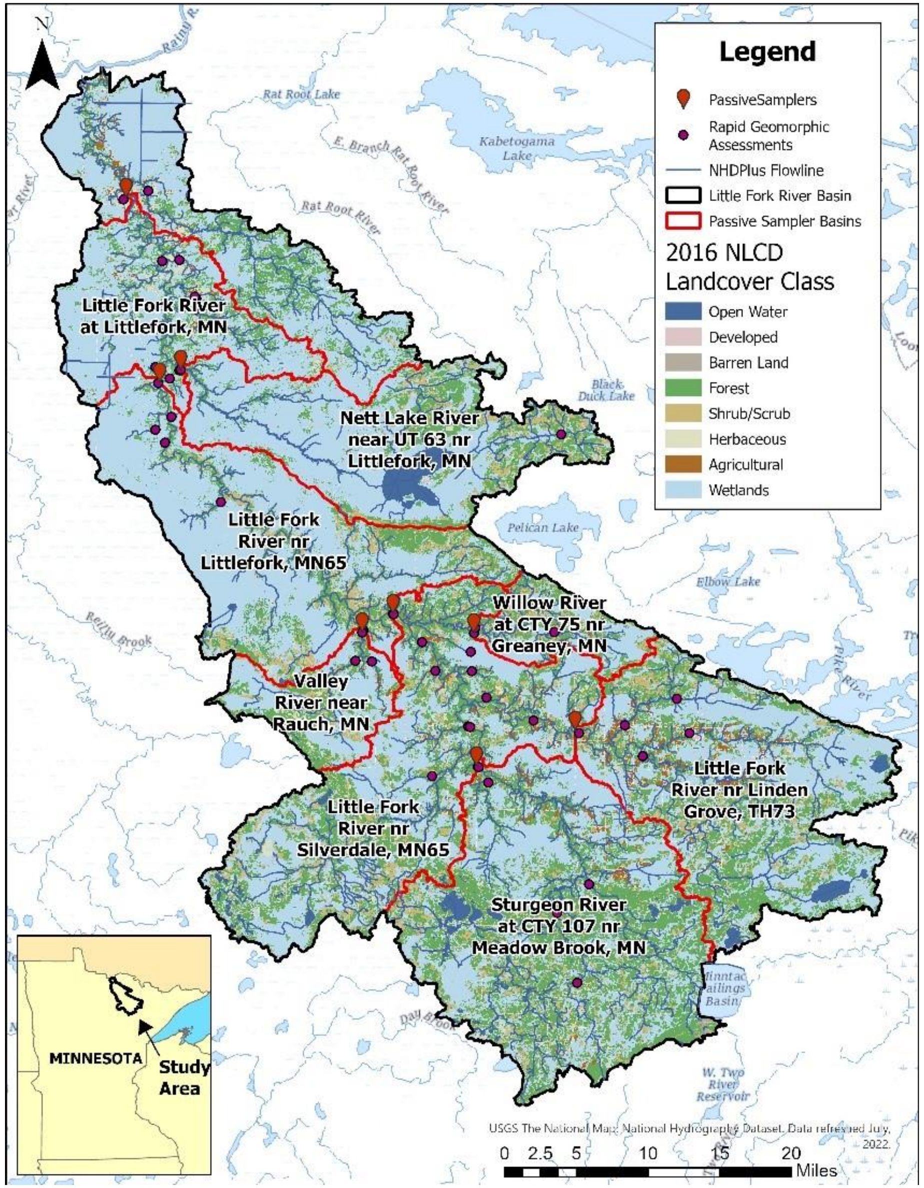
Little Fork Sediment Budget Development - Approach

- Selection of representative reaches – ephemeral and perennial channels
- Range of stream order, channel slope, valley side slopes, and riparian land cover
- Collection of field measurements of bank erosion and soft streambed sediment deposition via rapid geomorphic assessments in summer 2021 (drought)
- Build a representative channel network in a geographic information system – expanded to ephemeral channels for better connectivity between fields and streams
- Apply reach results for bank erosion and sediment deposition to the entire network
- This study wanted to especially characterize ravine erosion
- 46% of basin is wetlands, with 19% peat bogs



Fitzpatrick, F.A., Sterner, S.P., Baker, A.C., Soderman, S.S., Gran, K.B., Kasun, A.P., Kennedy, M.J., Norvitch, P., Anderson, J.P., and Gutzmann, M.E., 2023, Stream Corridor Sediment Budget for Watershed Sediment Source Apportionment for the Forested Little Fork River, Minnesota: Federal Interagency Sedimentation and Hydrologic Modeling Conference (SedHyd) 2023 Conference Proceedings, May 8-12, 2023, St. Louis, MO, [71.pdf (sedhyd.org)]

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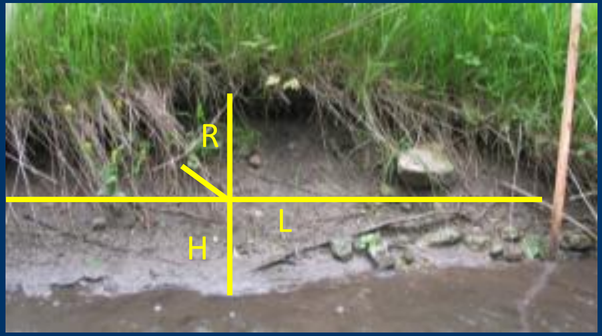
Little Fork Rapid Geomorphic Assessments

- Ephemeral to perennial channels with representative stream order and slopes
- Measure eroding banks and soft sediment deposition
- Measure channel morphology
- Reconnaissance level geomorphic and sediment process indicators
- Collect soft sediment and eroding bank samples for fingerprinting
- Reach-scale results applied to stream network-based corridor budget

Sediment Budget Methods –
Field Measurements of Erosion and Deposition

Inputs

BANK (SOURCE INPUT)

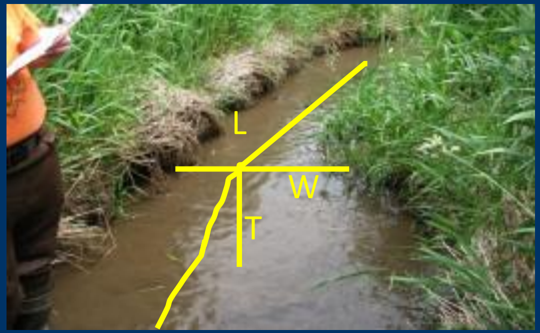


$$V = L \times H \times R$$

L = Length of eroding bank (m)
H = Height of eroding bank (m)
R = bank retreat rate (cm/yr)*
V = volume of eroded sediment (m^3/yr)

Storage

BED SEDIMENT (STORAGE)



$$V = L \times W \times T$$

L = Length of soft sediment (m)
W = Width of soft sediment (m)
T = thickness (m)
V = volume of stored soft sediment (m^3)

Sediment Budget Methods – Estimating Erosion Rates

Lateral Recession Rate ft/yr (cm/yr)	Category	Description
0.01-0.05 (0.3 - 1.5)	Slight	Some bare bank but active erosion not readily apparent. Some rills but no vegetative overhang. No exposed tree roots.
0.06-0.2 (1.8 – 6.0)	Moderate	Bank is predominantly bare with some rills and vegetative overhang. Some exposed tree roots but no slumps or slips.
0.3-0.5 (7.0 – 15)	Severe	Bank is bare with rills and severe vegetative overhang. Many exposed tree roots and some fallen trees and slumps or slips. Some changes in cultural features such as fence corners missing and realignment of roads or trails. Channel cross section becomes U-shaped as opposed to V-shaped.
0.5+ (>15)	Very severe	Bank is bare with gullies and severe vegetative overhang. Many fallen trees, drains and culverts eroding out and changes in cultural features as above. Massive slips or washouts common. Channel cross section is U-shaped and stream course may be meandering.

Natural Resources Conservation Service Wisconsin 2016. Streambank Erosion Prediction: Field Office Technical Guide, United States Department of Agriculture. Retrieved January 18, 2022 from https://efotg.sc.egov.usda.gov/#/state/WI.

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Sediment Budget Methods – Estimating Sediment Density

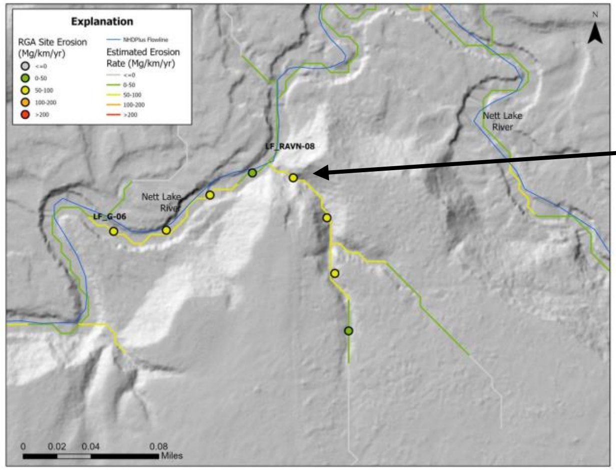
Soil Texture	Volume-Weight (Pounds/ft^3)
Gravel	110
Sand	105
Fine Sandy Loam	100
Loamy Sand	100
Sandy Loam	100
Loam	90
Sandy Clay Loam	90
Clay Loam	85
Silt Loam	85
Silty Clay	85
Silty Clay Loam	85
Silt	80
Clay	65
Organic	22

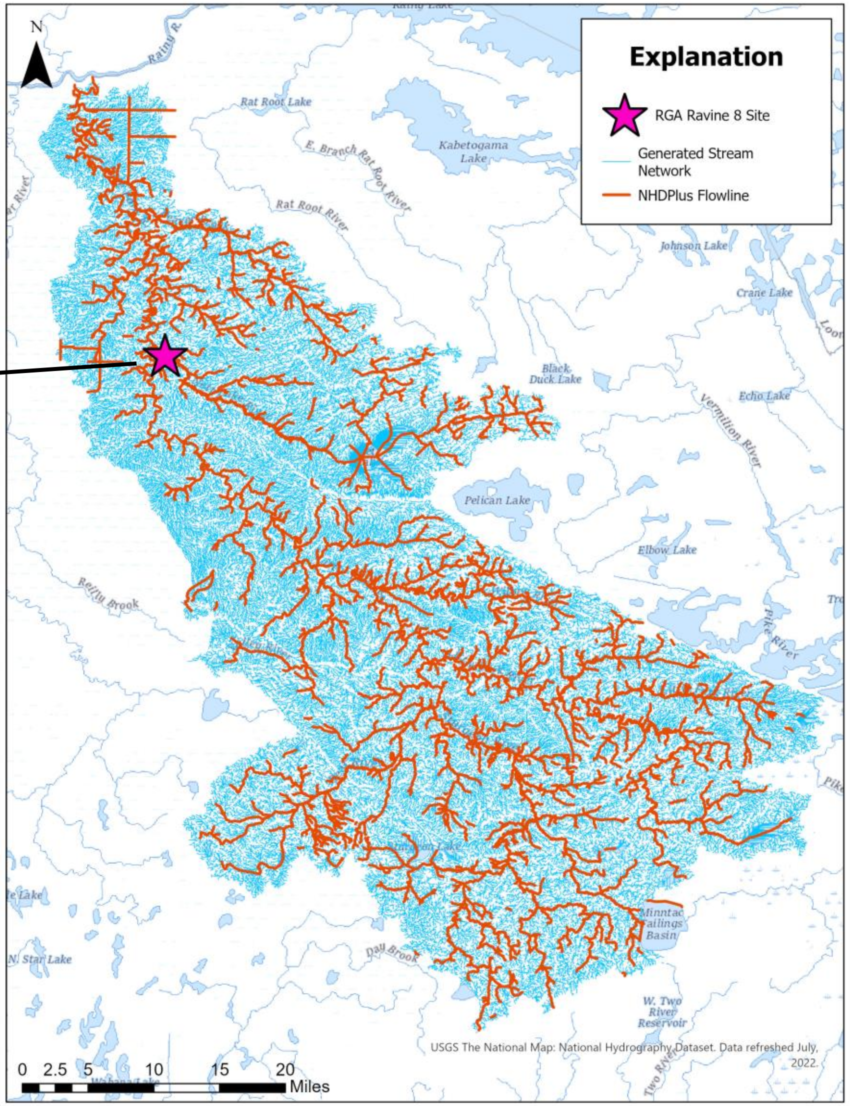
Natural Resources Conservation Service Wisconsin 2016. Streambank Erosion Prediction: Field Office Technical Guide, United States Department of Agriculture. Retrieved January 18, 2022 from https://efotg.sc.egov.usda.gov/#/state/WI.

Peppler, M.C. and Fitzpatrick, F.A. 2018. "Collection methods, data compilation, and lessons learned from a study of stream geomorphology associated with riparian cattle grazing along the Fever River, University of Wisconsin Platteville Pioneer Farm, Wisconsin, 2004–11," U.S. Geological Survey Open-File Report 2016–1179.

Little Fork GIS-based Stream Network Sediment Budget

- Built new stream network from hydro-enforced 10-m Digital Elevation Model using a watershed threshold of 0.02 square kilometers.
  - added 3 stream orders of headwater dry channels not covered by the National Hydrologic Dataset (USGS, 2018)
- Divided into 60-m segments and calculated channel slope, valley side slopes, stream order, and drainage area.
- Ravine channels could be distinguished from headwater wetland swales based on channel slopes and presence of steep side slopes

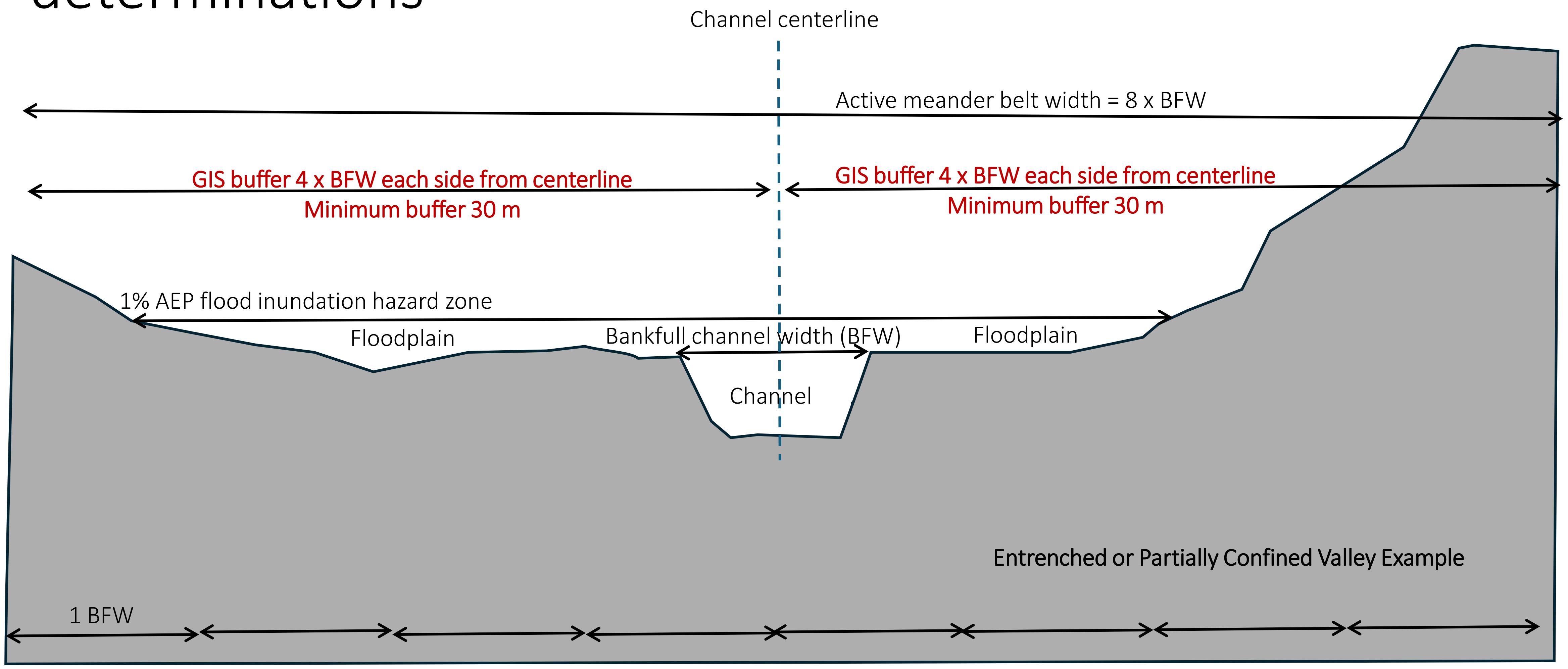




Little Fork watershed, Minnesota

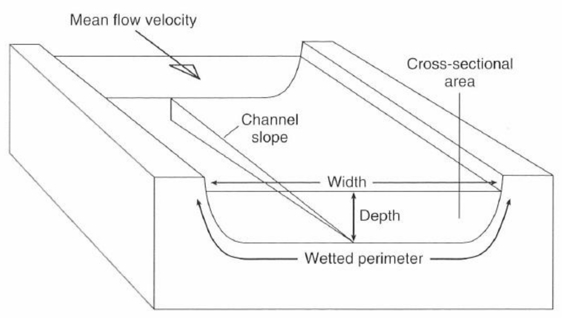
Fitzpatrick et al., 2023

Linked steep side slopes to erosion potential using fluvial hazard zone/active meander belt buffer determinations



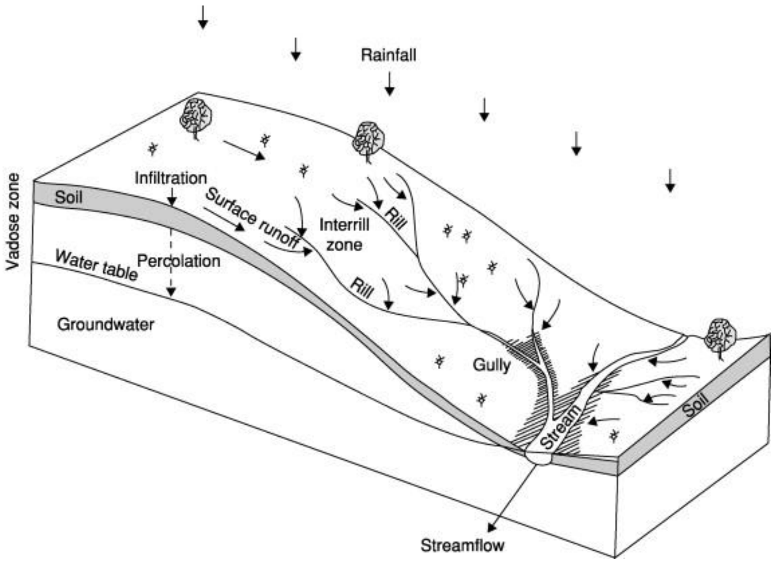
Sediment Budget Development – includes dry channels

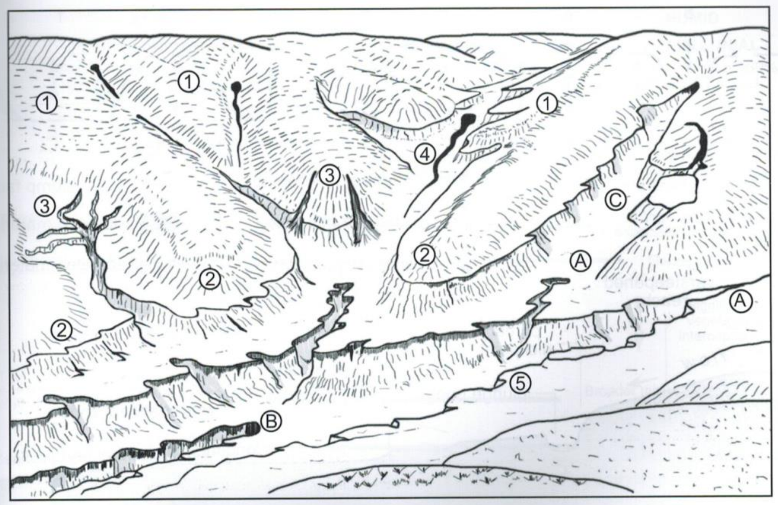
- Channel = concentrated flows with a visible bank and bed. Transition from gullies in steep areas. Can be ephemeral, intermittent, or perennial
- Typically processes along ephemeral channels are missing from watershed models and TMDLs
- Many of these channels are hiding in the woods, ready to give to downstream areas during floods.



Discharge = Cross-sectional area x Mean flow velocity
Hydraulic radius = Cross-sectional area/wetted perimeter

Figure 6.1 Basic channel parameters. After Summerfield (1991).

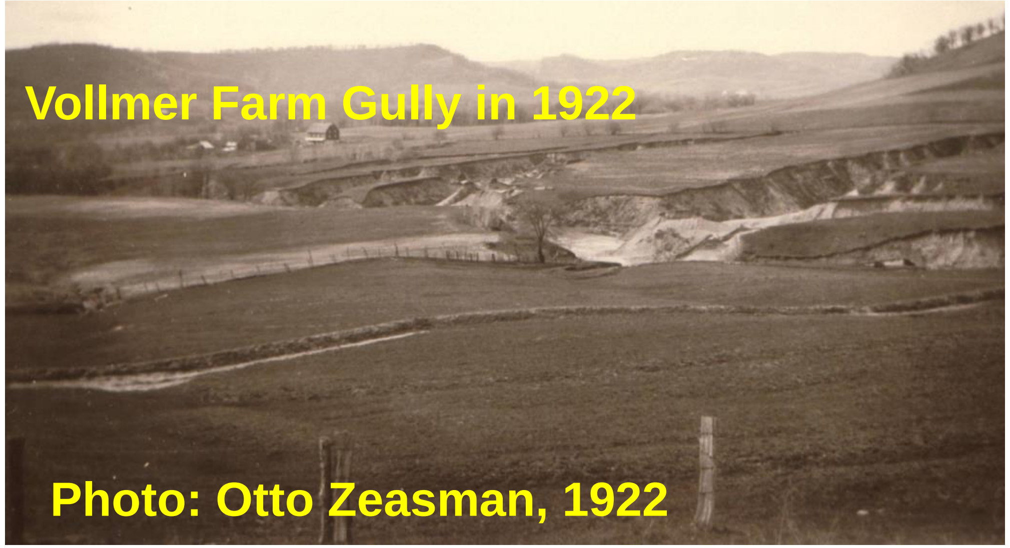


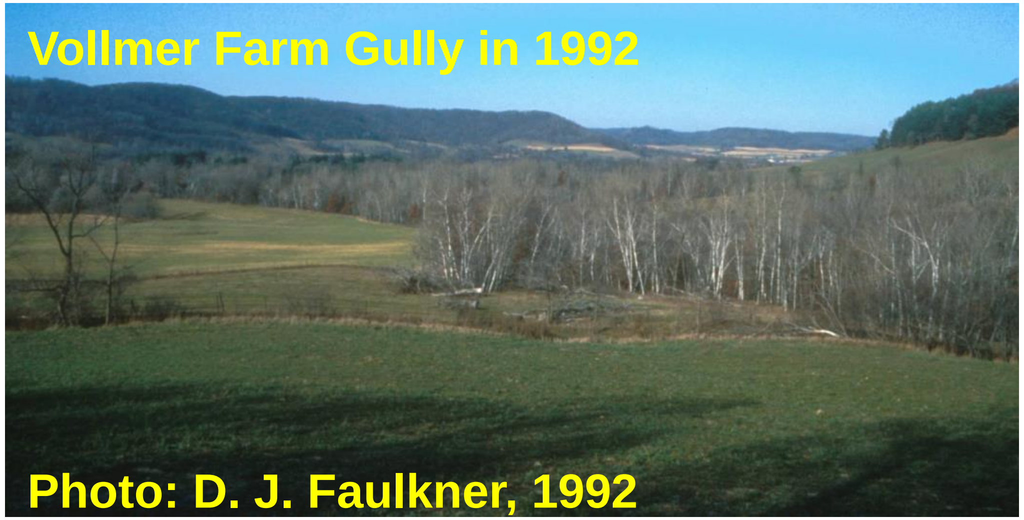


Types of drainage lines
① interrill ② rill ③ gully ④ incised channel - discontinuous
⑤ incised channel - continuous
Incised channel forms
Ⓐ primary headcut Ⓑ secondary headcut Ⓒ intact valley fill

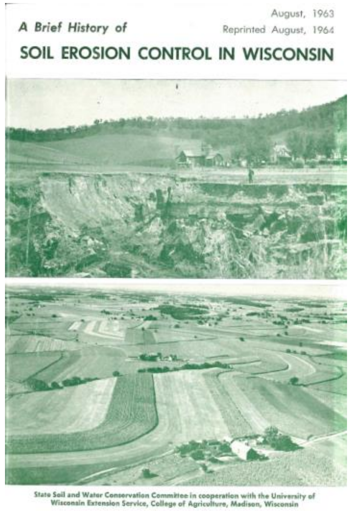
Figure 4.8 Channelised flow. Rills and gullies develop on hillslopes, whereas incised and discontinuous channels form on valley floors. Incision is initially triggered by a primary headcut. Subsequent bed level adjustments are induced by secondary headcuts. Modified from Schumm *et al.* (1984) (Fig 6.7). © Water Resources Publications. Reproduced with permission.

Why account for gullies, ravines, and ephemeral channels? Recent flood-related reactivation of widespread headward erosion in steep areas





Professor O.R. Zeasman


A Brief History of

August, 1963
Reprinted August, 1964

SOIL EROSION CONTROL IN WISCONSIN

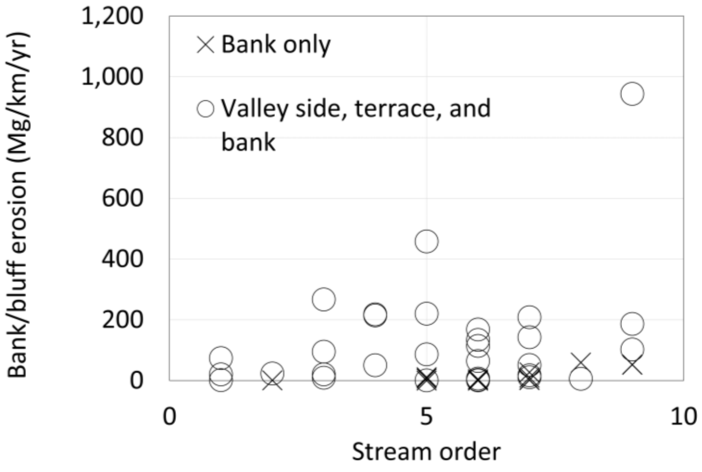
State Soil and Water Conservation Committee in cooperation with the University of Wisconsin Extension Service, College of Agriculture, Madison, Wisconsin

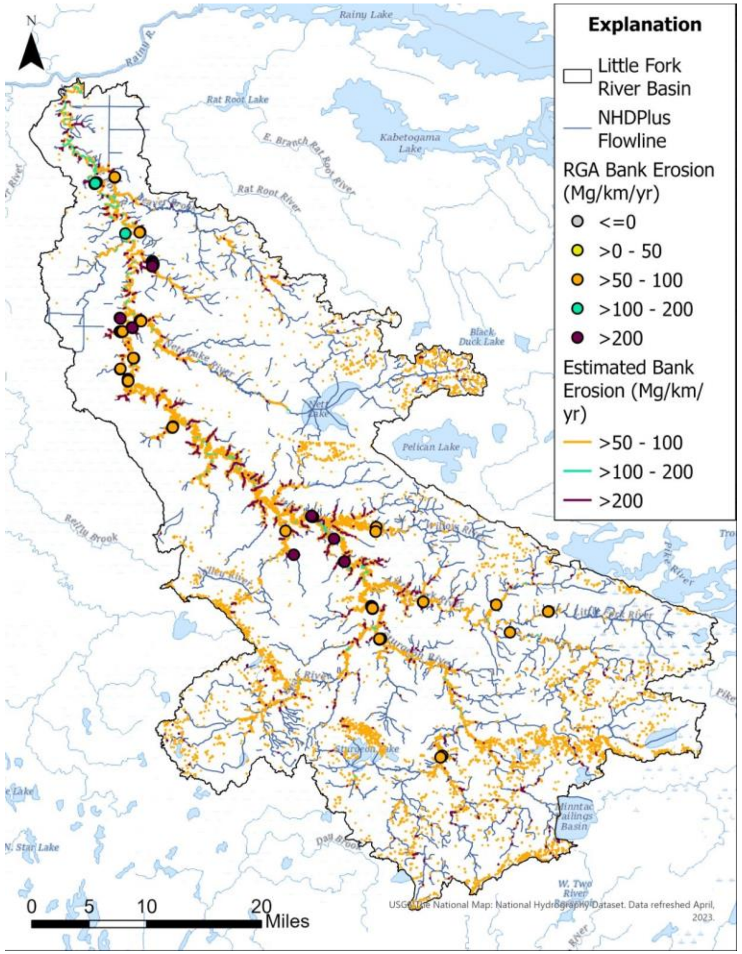
Ryan Creek, 2024, looking downstream, 2018(?) flood-related drop inlet dam breach and upstream erosion along valley side

Little Fork Bank Erosion

Sources of Sediment—ravines, banks, terraces, and valley sides

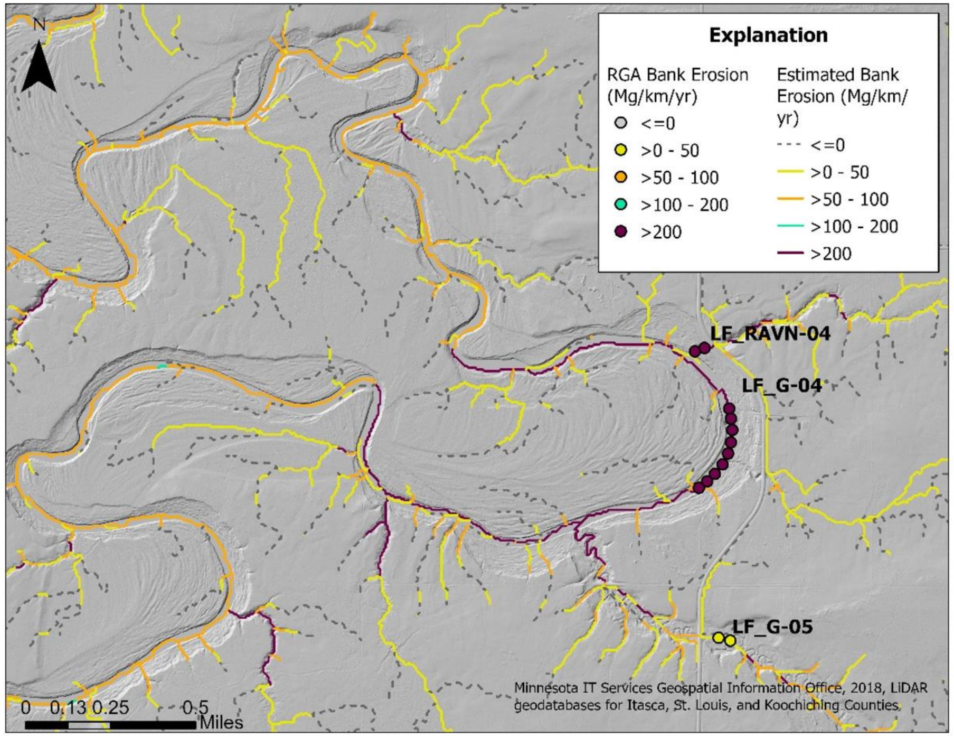
- Erosion rates measured at Rapid Geomorphic Assessment (RGA) reaches were as high as 900 Mg per kilometer per year
- High erosion rates, and steep channel slopes were notable for ravines along the main stem

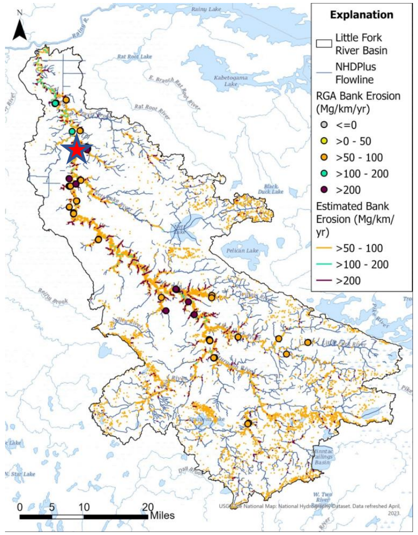




Fitzpatrick et al., 2023

Examples of highest erosion rates in a Little Fork main stem and ravine





Highest erosion area related to post-glacial geomorphic setting at a knickpoint

Fitzpatrick et al., 2023

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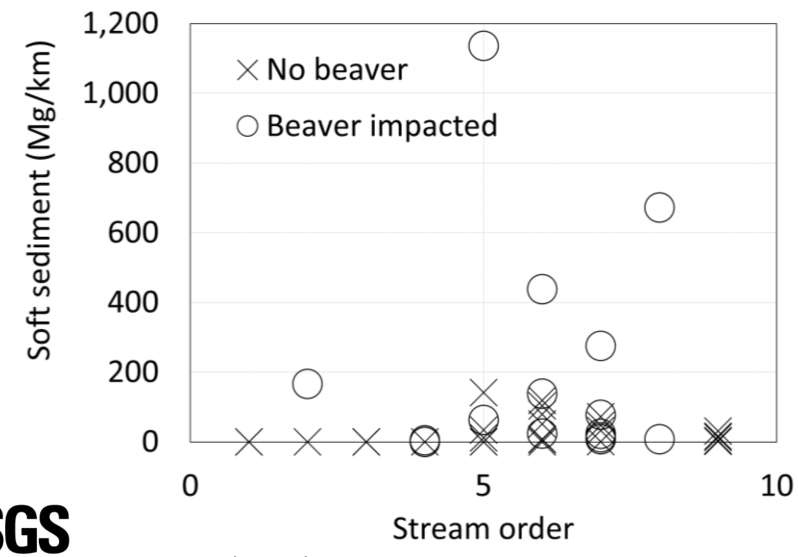
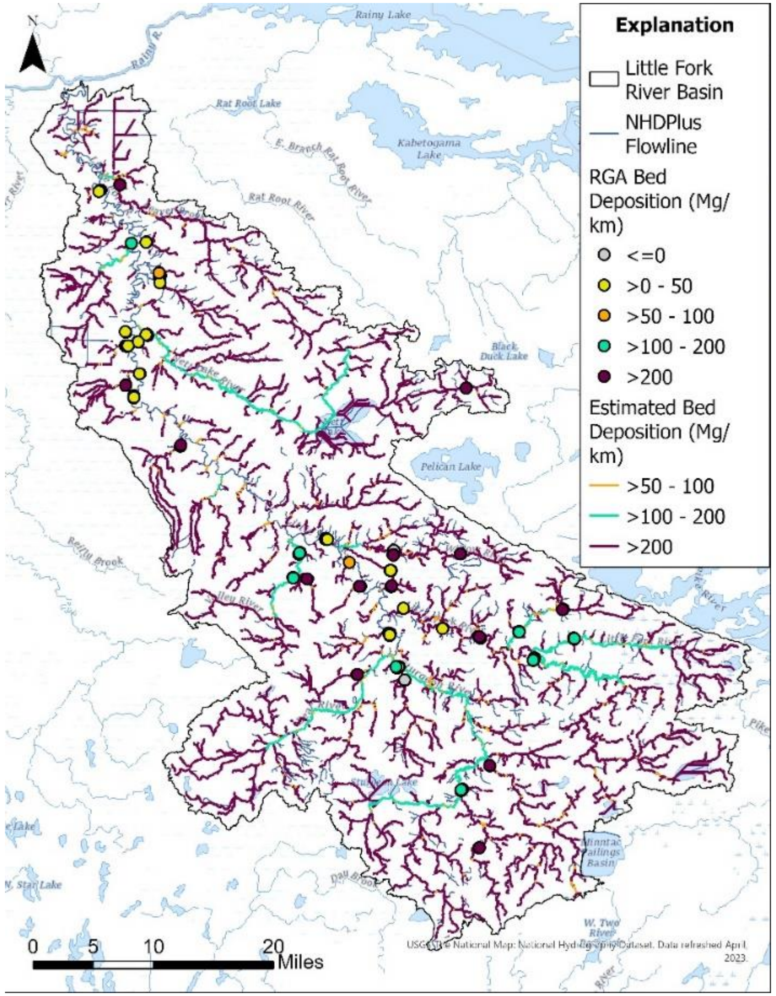
Little Fork Soft Sediment Deposition

- Soft sediment deposition was highly variable and depending on the where the RGA was located relative to beaver activity
- Used mean values for both beaver and no beaver reaches based on stream order and slope
- Highest value was from a RGA with a beaver impoundment





Fitzpatrick et al., 2023

Little Fork Sediment Budget shows importance of being able to map and account for erosion/deposition in dry headwater channels

Stream Level	Valley Sides	Channel Slope	Total Length	Erosion		Bed Deposition		Deposition : Erosion
(Units)	Steep (>15%)	%	km	Mg/year	Mg/km/year	Mg	Mg/km	Years
Headwaters	No	< 1	23,000	1,600	0	400,000	17	250
Headwaters	No	1-2	2,500	160	0	11,000	5	69
Headwaters	No	> 2	1,800	12,000	7	1,800	1	0
Headwaters	Yes	< 1	620	3,600	6	15,000	25	4
Headwaters	Yes	1-2	190	10,000	53	960	5	0
Headwaters	Yes	> 2	880	52,000	60	730	1	0
Perennial Tributaries	No	< 1	1,100	8,400	7	170,000	150	20
Perennial Tributaries	No	1-2	36	77	2	1,500	41	20
Perennial Tributaries	No	> 2	12	59	5	630	51	11
Perennial Tributaries	Yes	< 1	340	12,000	35	35,000	100	3
Perennial Tributaries	Yes	1-2	42	5,700	140	1,800	42	0
Perennial Tributaries	Yes	> 2	20	4,300	210	860	43	0
Mainstem	No	< 1	22	1,300	58	1,500	70	1
Mainstem	No	1-2	0	2	22	3	35	2
Mainstem	No	> 2	0	0	0	0	0	0
Mainstem	Yes	< 1	220	22,000	100	14,000	63	1
Mainstem	Yes	1-2	5	470	93	54	11	0
Mainstem	Yes	> 2	1	140	97	5	4	0
Total			**30,789**	**133,807**		**654,842**		**5**

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Fitzpatrick et al., 2023

Sediment Fingerprinting with Sed_SAT Tool

Prep data for analysis

Transform non-normal data by tracer within each source group (Shapiro-Wilk test)

↓

Remove outliers in each source type (3 standard deviation rule)

↓

Normalize data based on **grain size** and **organic content**

↓

Bracket fluvial samples by sources (**ensure tracer conservativeness**)

↓

Transform non-normal data for each tracer grouped by all sources (Multivariate normality test)

↓

Identify tracers that significantly distinguish source types with

Stepwise Discriminant Function Analysis

↓

Final source apportionment

Unmixing Model

↓

Error Analysis

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Sed fingerprinting tool (Gorman-Sanisaca, Gellis, and Lorenz, 2017)

Sed_SAT Error Analyses Tools

- Helps to make sure source samples are correctly classifying and seeing where there may be some overlap
  - Confusion Matrix – Percentage of source samples correctly classified by the final set of tracers in the stepwise discriminant function analysis
  - Source Verification Tests (SVT) – Runs each source sample as a target sample and checks for possible misclassification as another source.
  - Monte Carlo leave-one-out cross validation – leaves one source sample out and repeats unmixing model for each target sample. Look for standard deviation of all runs of less than 5%.

Sed fingerprinting tool (Gorman-Sanisaca, Gellis, and Lorenz, 2017)

Kinnickinnic River, Milwaukee, Wisconsin

Possible sources: industrial commercial, residential, green space, streambank

Targets – soft streambed sediment and suspended sediment

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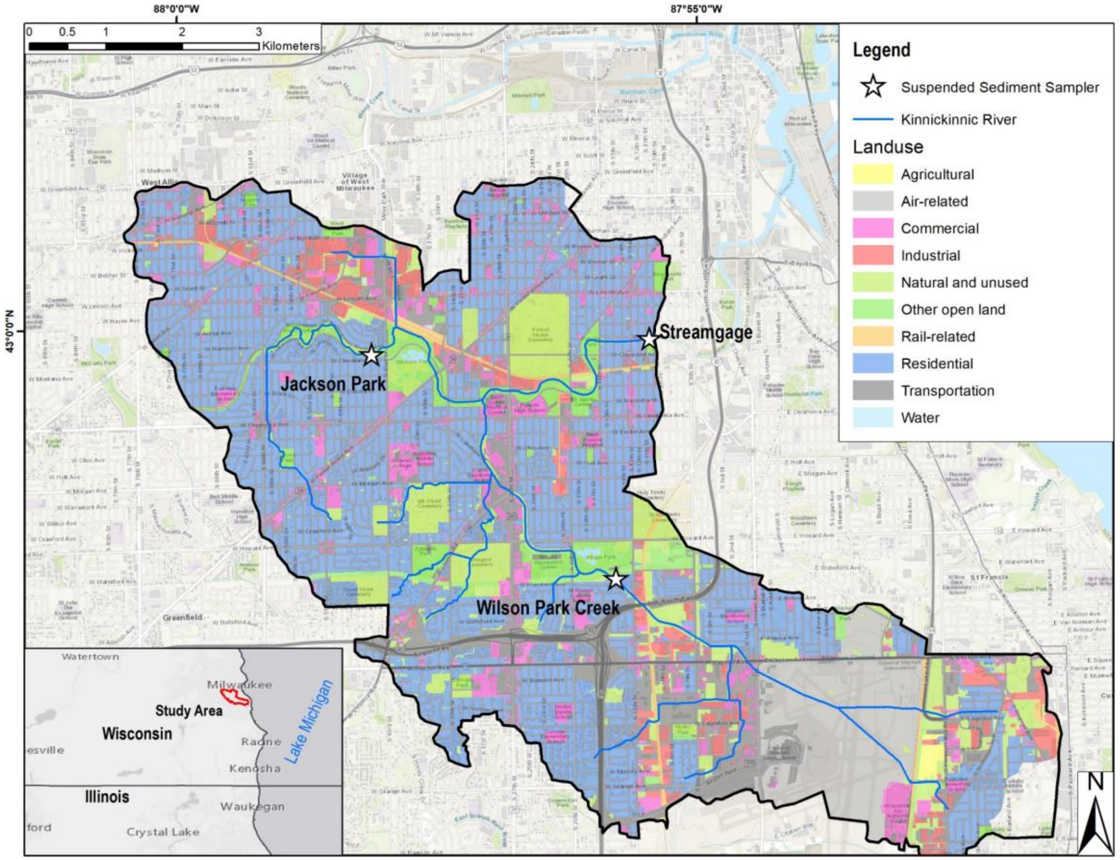
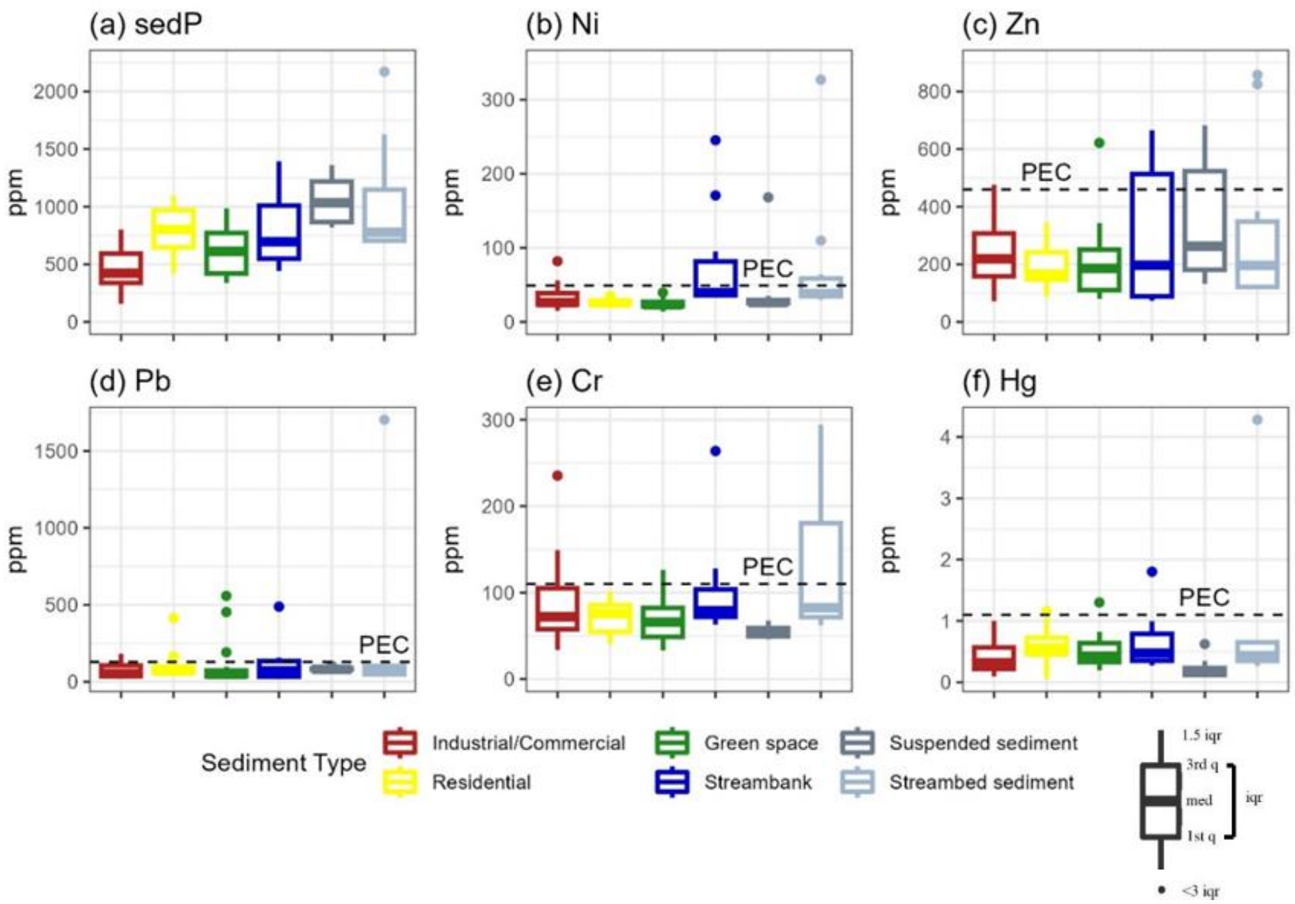


Blount et al., 2023, Stream corridor sources of suspended sediment and sediment-bound phosphorus from an urban tributary to the Great Lakes
https://www.sedhyd.org/2023Program/1/264.pdf

Kinnickinnic River, Milwaukee, Wisconsin

Geochemistry by Source and Sink



Blount et al., 2023

Stream Corridor Sediment Budget

Basin	Stream length (km)	Bank erosion (mT/yr)	Bank erosion sedP (kg/yr)	Streambed sediment (mT)	Streambed sedP (kg)
JP (north) Branch	5.4	600	370	170	46
WPC (south) Branch	12.5	75	97	210	300
Full network at streamgage	35.2	1100	780	470	470

Kinnickinnic TMDL

- TSS – TMDL estimated 2400 mT/yr
- TP - TMDL estimated 5800 kg/yr

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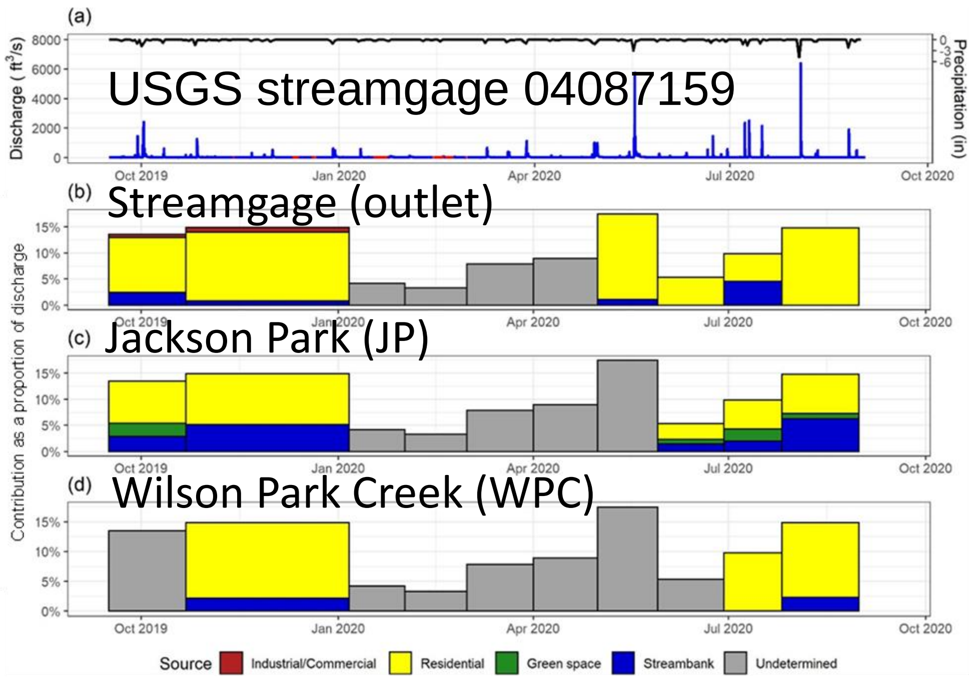
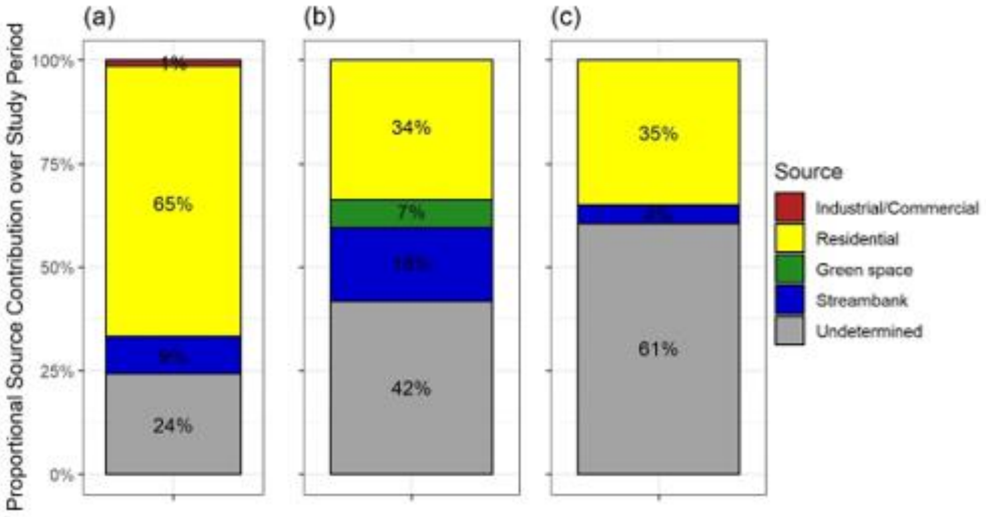
Kinnickinnic River, Milwaukee, Wisconsin

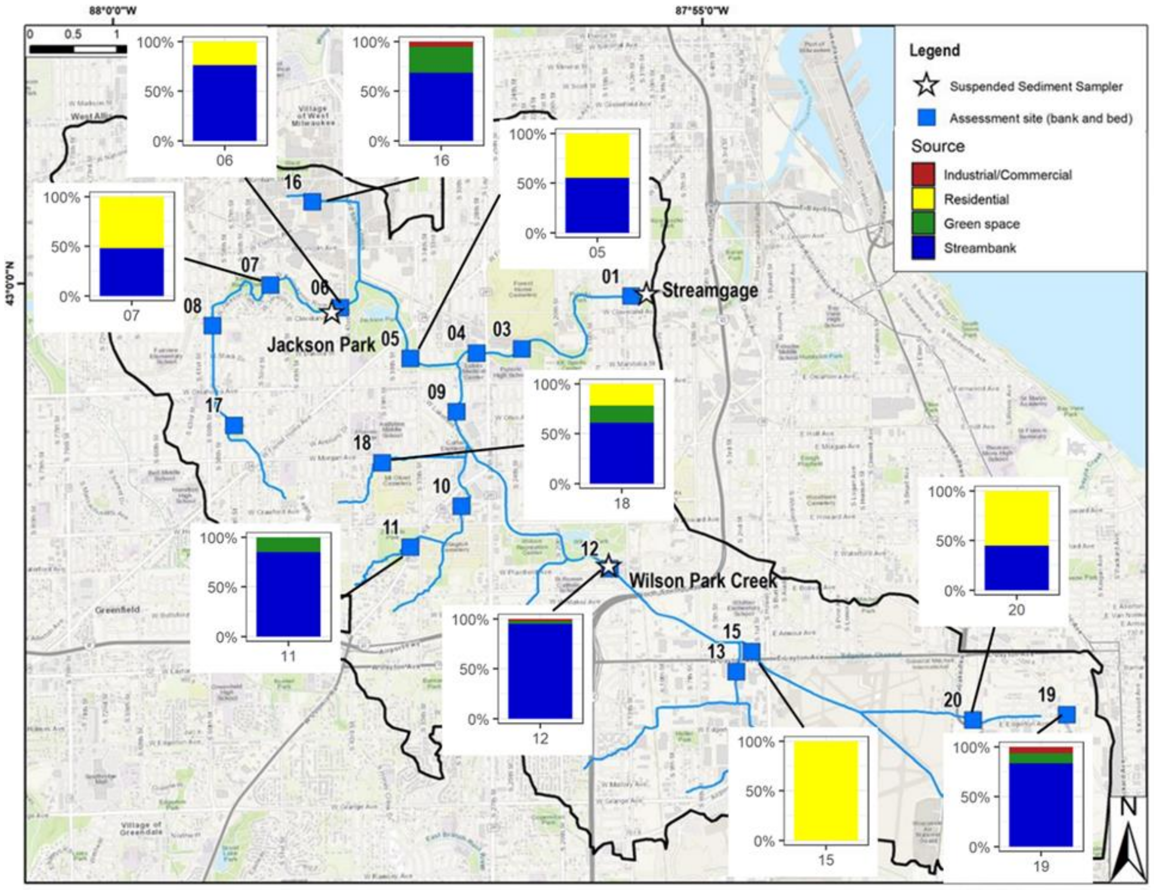




Streamgage JP WPC

Suspended sediment

Possible sources: industrial commercial, residential, green space, streambank



Streambed sediment

Blount et al., 2023

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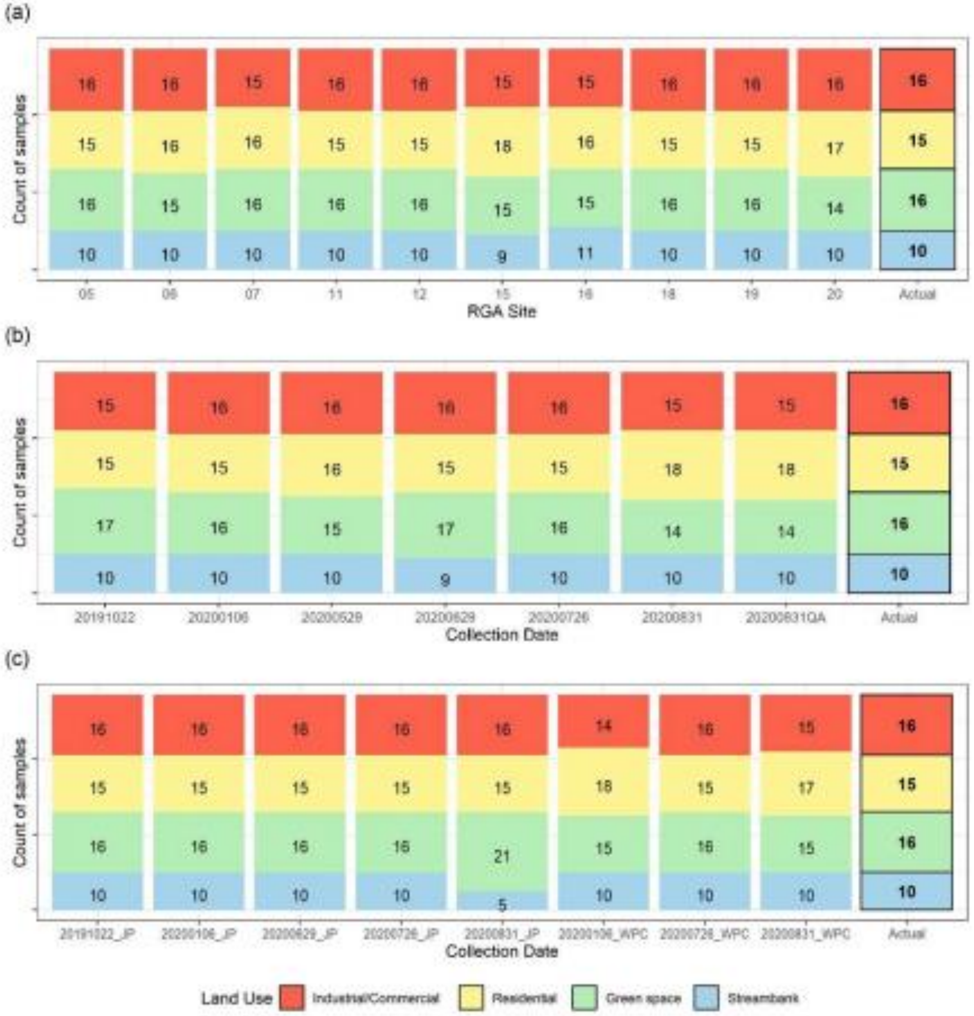
Kinnickinnic River Source Verification Tests



- Source Verification Tests (SVT) – Runs each source sample as a target sample and checks for possible misclassification as another source.
- Distinct fingerprints for industrial commercial, residential, green space, and streambanks sources for both suspended and streambed samples

Blount et al., 2023

J Soils Sediments
DOI 10.1007/s11368-013-0771-6

WATERSHED SEDIMENT SOURCE IDENTIFICATION: TOOLS, APPROACHES, AND CASE STUDIES

Sediment source analysis in the Linganore Creek watershed, Maryland, USA, using the sediment fingerprinting approach: 2008 to 2010

Allen C. Gellis · Gregory B. Noe

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
Vol. 54, No. 6 AMERICAN WATER RESOURCES ASSOCIATION December 2018

Sediment Fingerprinting to Delineate Sources of Sediment in the Agricultural and Forested Smith Creek Watershed, Virginia, USA

A.C. Gellis and L. Gorman Sanisaca

Journal of Environmental Management 333 (2023) 117254

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ELSEVIER

Research article

Building a library of source samples for sediment fingerprinting – Potential and proof of concept

Tanja N. Williamson [a,*], Faith A. Fitzpatrick [b], Rebecca M. Kreiling [c]

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Check for updates

https://doi.org/10.1016/j.jenvman.2023.117254

Findable

Accessible

Interoperable

Reusable

Library of source samples

Journal of Environmental Quality TECHNICAL REPORTS
LANDSCAPE AND WATERSHED PROCESSES

Stream Sediment Sources in Midwest Agricultural Basins with Land Retirement along Channel

T. N. Williamson,* V. G. Christensen, W. B. Richardson, J. W. Frey, A. C. Gellis, K. A. Kieta, and F. A. Fitzpatrick

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Prepared in cooperation with the Little River Water-Quality Consortium

Multiple-Source Tracking: Investigating Sources of Pathogens, Nutrients, and Sediment in the Upper Little River Basin, Kentucky, Water Years 2013–14

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Stream Corridor Sources of Suspended Sediment and Phosphorus from an Agricultural Tributary to the Great Lakes

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SEDIMENT FINGERPRINTING IN THE CRITICAL ZONE

CrossMark

Combining sediment fingerprinting with age-dating sediment using fallout radionuclides for an agricultural stream, Walnut Creek, Iowa, USA

Allen C. Gellis [1] · Christopher C. Fuller [2] · Peter Van Metre [3] · Christopher T. Filstrup [4] · Mark D. Tomer [5] · Kevin J. Cole [5] · Timur Y. Sabitov [6]

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Monthly suspended-sediment apportionment for a western Lake Erie agricultural tributary

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Stream corridor and upland sources of fluvial sediment and phosphorus from a mixed urban-agricultural tributary to the Great Lakes

James D. Blount [a], Leah E.K. Lenoch [b], Faith A. Fitzpatrick [a]

Lessons learned

- Estimates of corridor erosion from the sediment budget could account for 60-170% of the average annual TSS load.
- Gully and ravine erosion is important in steep watersheds and along mainstem valley sides, related to geomorphic setting
- Detailed channel network was necessary to build to account for what's happening in ephemeral channels.
- Suspended and bed sediment may have higher phosphorus concentrations than source sediment, especially in watersheds with a large dissolved phosphorus load.
- Volume of soft fine-grained sediment stored in channels can vary and is important to consider in potential lag times for observing water quality improvements at downstream monitoring locations. Fingerprinting can show how upland sources in headwater channels are overwhelmed by bank signatures downstream
- A library of upland source fingerprints across watersheds in the Midwest may help to reduce the number of source samples that need to be collected.

Selected Publications

Fitzpatrick et al., 2023, Stream Corridor Sediment Budget for Watershed Sediment Source Apportionment for the Forested Little Fork River, Minnesota https://www.sedhyd.org/2023Program/1/71.pdf

Baker et al., [in review], Tracking fluvial sediment and phosphorus from headwaters to mainstem in the Little Fork River, a forested subwatershed of Lake of the Woods (journal submission)

Blount et al., 2023, Stream corridor sources of suspended sediment and sediment-bound phosphorus from an urban tributary to the Great Lakes https://www.sedhyd.org/2023Program/1/264.pdf

Williamson et al., 2023, Building a library of source samples for sediment fingerprinting – Potential and proof of Concept, Journal of Environmental Management https://doi.org/10.1016/j.jenvman.2023.117254

Broerman et al., [in review], Sources and storage of streambed sediment and sediment-bound phosphorus in an agricultural Great Lakes tributary, journal submission – WI AWRA presentation on 4/10/2025.

Thank you!!

For more info:

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Photos: Kinnickinnic River, Milwaukee, WI; October 2019, J. Blount