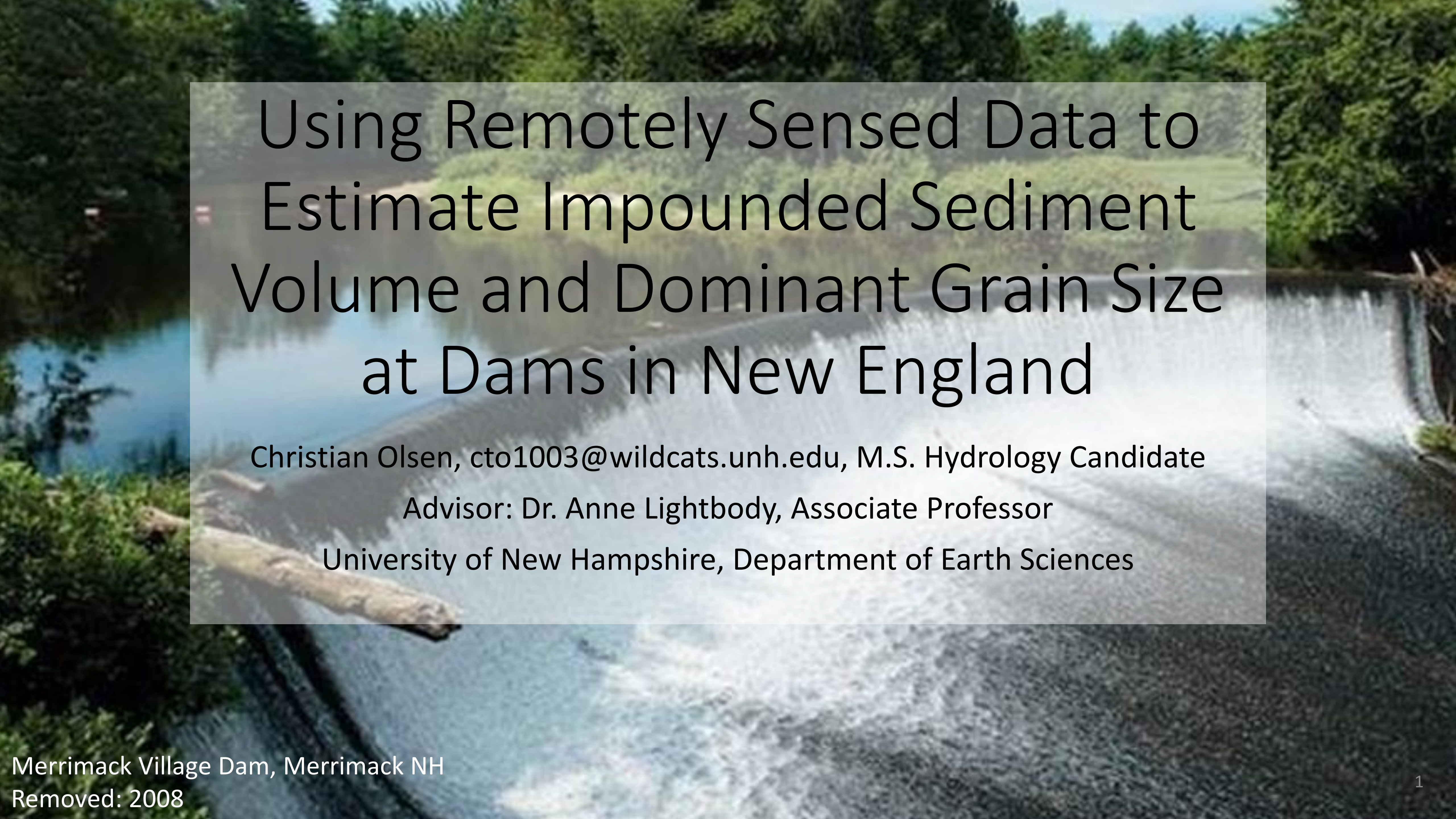
Using Remotely Sensed Data to Estimate Impounded Sediment Volume and Dominant Grain Size at Dams in New England

Christian Olsen, cto1003@wildcats.unh.edu, M.S. Hydrology Candidate
Advisor: Dr. Anne Lightbody, Associate Professor
University of New Hampshire, Department of Earth Sciences



Merrimack Village Dam, Merrimack NH
Removed: 2008

Funding and Acknowledgments

Pascale Biron and Guénolé Choné (Concordia University) for sharing their ArcGIS plug-in for delineating bankfull widths from LiDAR-derived digital elevation models (DEMs).

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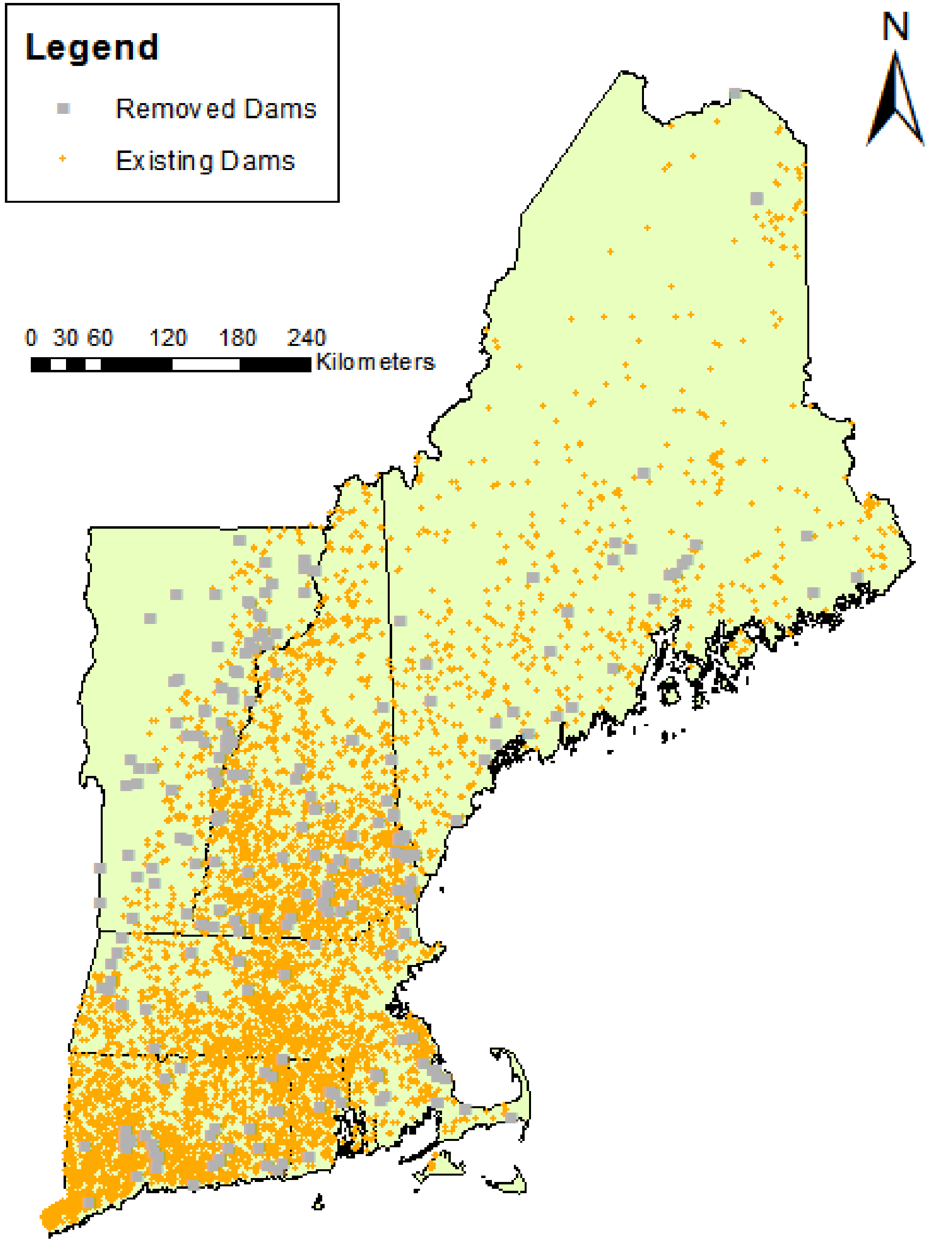
Merrimack Village Dam, Merrimack NH
Removed: 2008

Dams in New England

- Over 7000 existing dams in New England
- Most built pre-1950s
- Many not used for there original purpose
- Management of all dams impossible

Macallen Dam, in Newmarket, NH



EPSCoR New England Dam Database (2018)

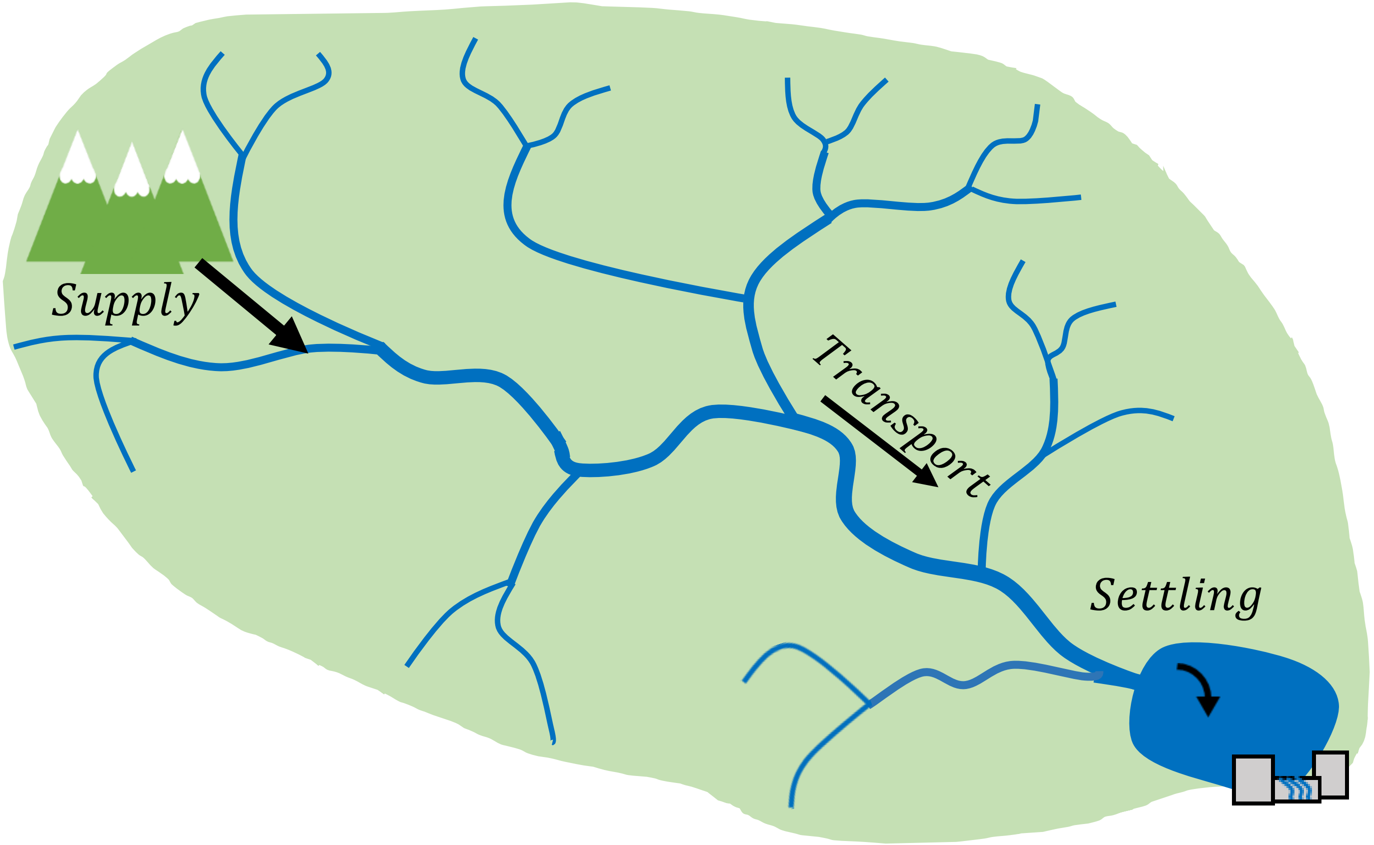
Impounded Sediment: A Challenge for Dam Managers

- Reduces reservoir storage capacity and functionality
- Increases the logistical complexity & cost of dam removal
- Can be contaminated, especially if fine grained

Conway Electric Reservoir Dam, Conway, MA

Controls on the Characteristics of Impounded Sediment

Image modified from David Simon



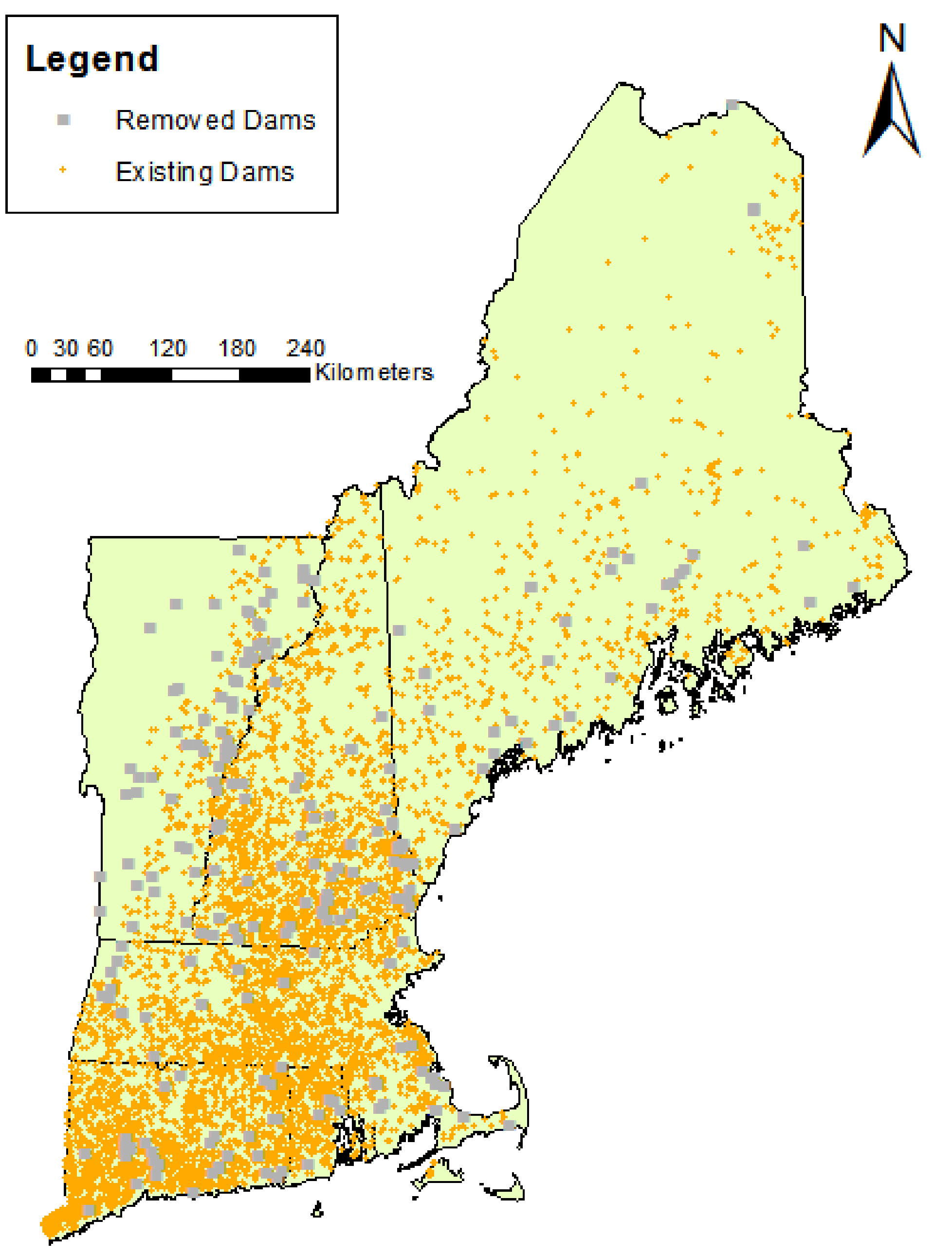
1) Sediment supply from watershed soil erosion ($Supply$) + 2) Sediment transported to dams via rivers and streams ($Transport$) + 3) Dam trap efficiency ($Settling$) = Volume and grain size of impounded sediment

Project Goal

- Develop a screening tool to estimate impounded sediment grain size, and volume at New England Dams

Research Questions

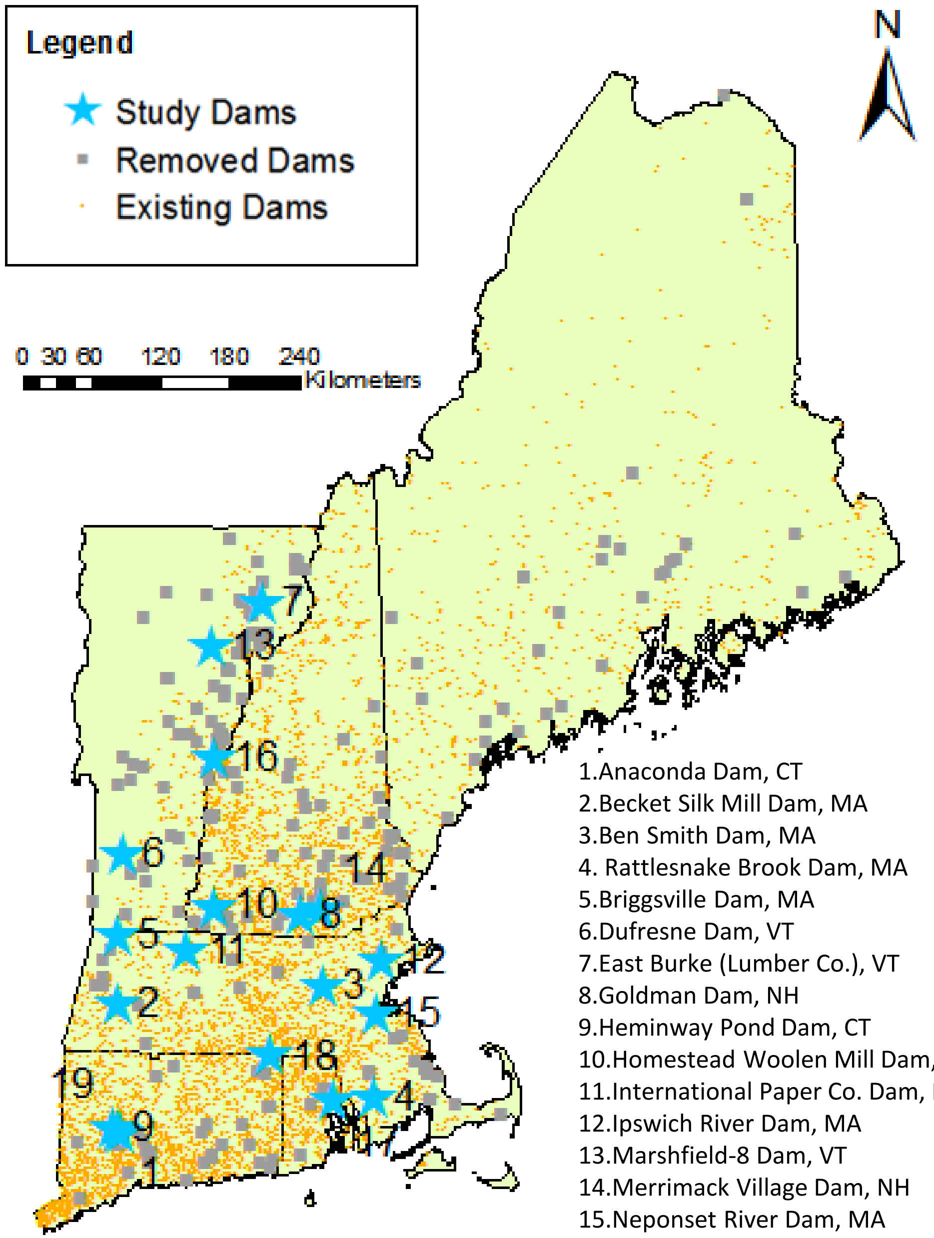
- How can the volume and dominant grain size of impounded sediment be best estimated using indices of sediment supply, transport, and settling?
- How can estimates of impounded sediment characteristics complement other dam datasets to inform dam removal tradeoffs?



EPSCoR New England Dam Database (2018)

Project Methods

- Cross site comparison of 19 dam sites (study dams) in New England
- Information on sediment volumes and grain sizes from previously conducted fieldwork
  - Dam removal feasibility reports
  - Dam safety inspections
  - Scientific studies

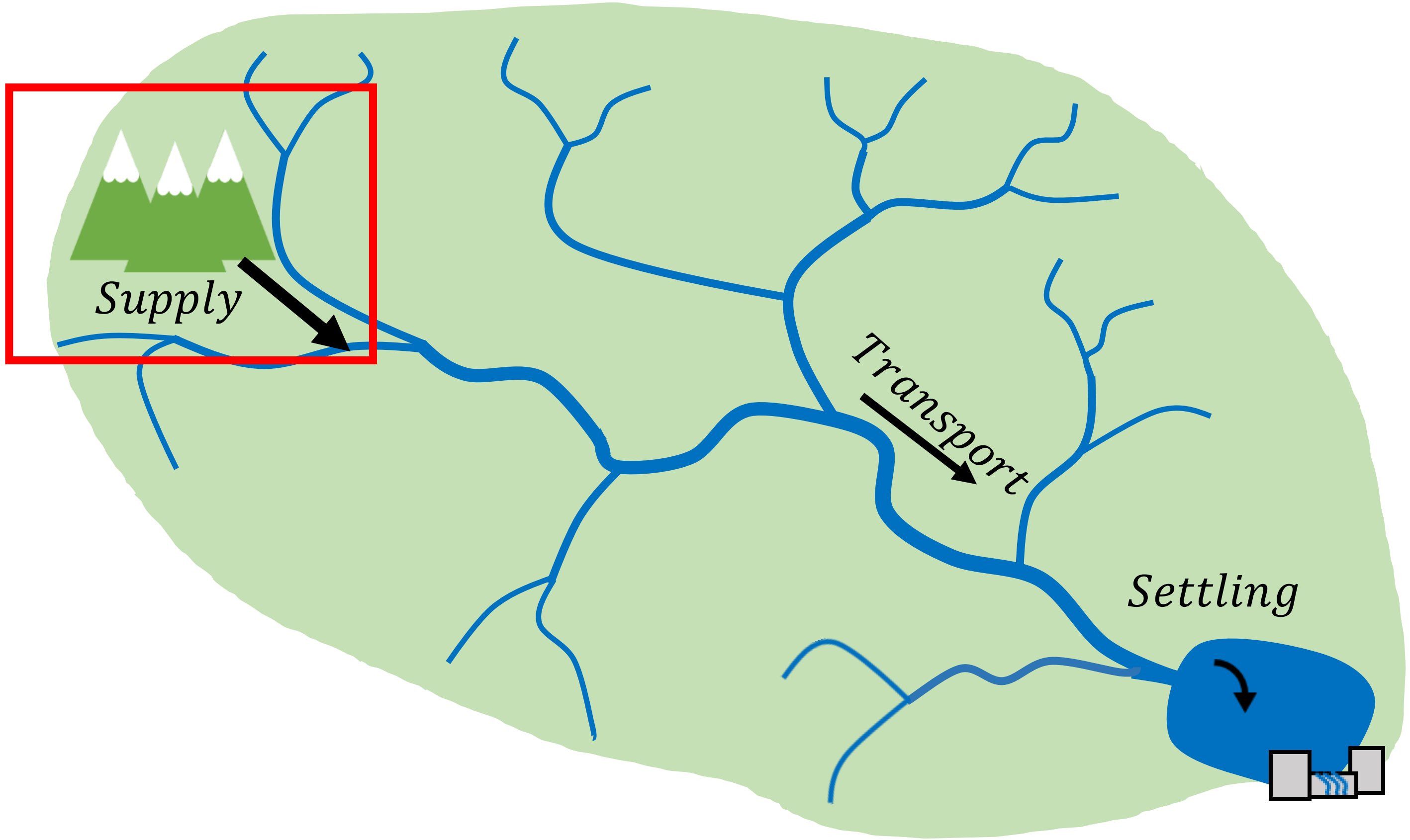


1.Anaconda Dam, CT
2.Becket Silk Mill Dam, MA
3.Ben Smith Dam, MA
4. Rattlesnake Brook Dam, MA
5.Briggsville Dam, MA
6.Dufresne Dam, VT
7.East Burke (Lumber Co.), VT
8.Goldman Dam, NH
9.Heminway Pond Dam, CT
10.Homestead Woolen Mill Dam, NH
11.International Paper Co. Dam, MA
12.Ipswich River Dam, MA
13.Marshfield-8 Dam, VT
14.Merrimack Village Dam, NH
15.Neponset River Dam, MA
16.Norwich Reservoir, VT
17.Pawtuxet Falls Dam, RI
18.Perryville Pond Dam, MA
19.Pin Shop Pond Dam, CT

EPSCoR New England Dam Database (2018)

Sediment Supply Index – Revised Universal Soil Loss Equation

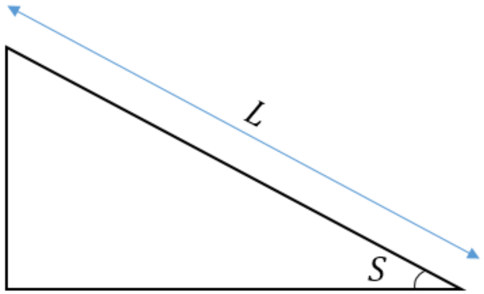
Image modified from David Simon



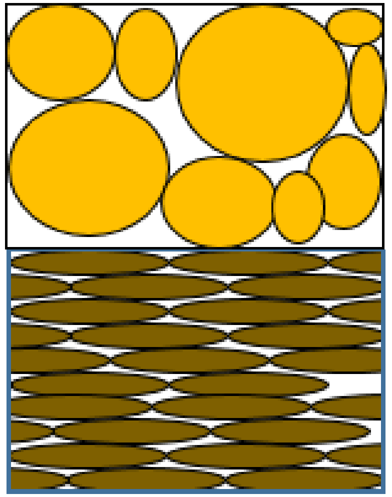
$$Y = R \times LS \times K \times P \times C$$

Y average annual soil loss per unit area
R erodibility due to precipitation
LS erodibility due to topographic factors
K erodibility due to intrinsic soil properties
P effect of soil conservation practice
C erodibility due to land cover

Sediment Supply Index – Revised Universal Soil Loss Equation



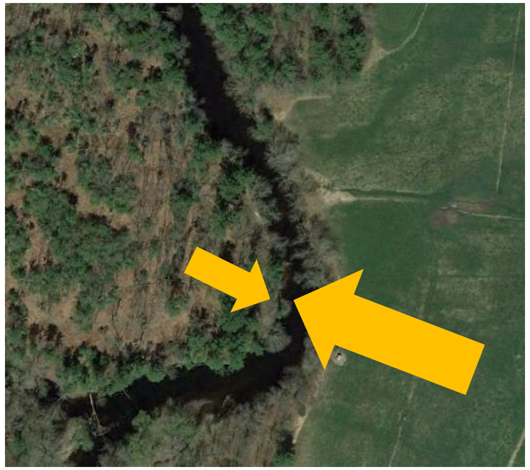
LS erodibility due to topographic factors



K erodibility due to intrinsic soil properties

P effect of soil conservation practice

R erodibility due to precipitation



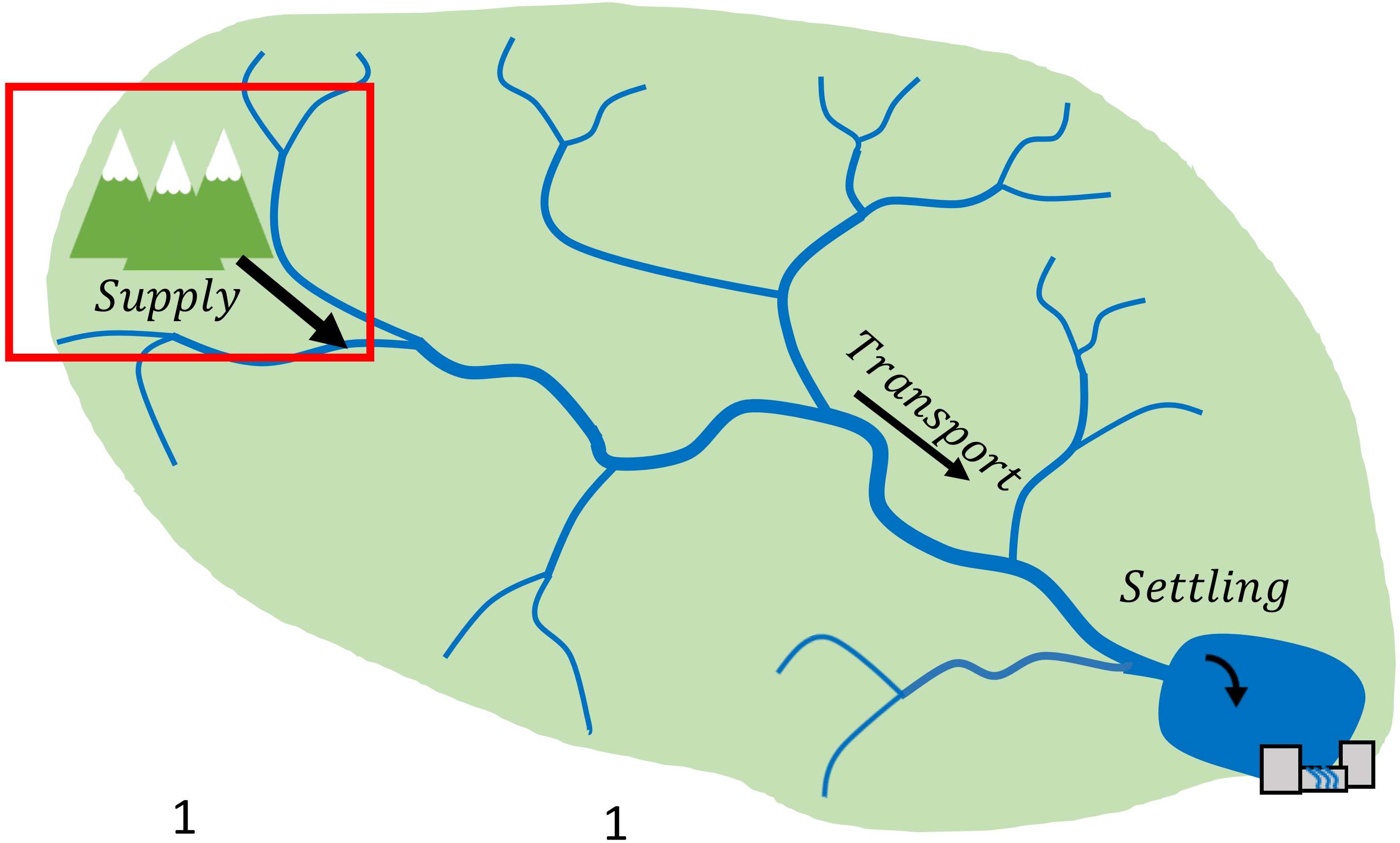
C erodibility due to land cover

$$Y = \boxed{R} \times \boxed{LS} \times \boxed{K} \times \boxed{P} \times \boxed{C}$$

Y average annual soil loss per unit area
R erodibility due to precipitation
LS erodibility due to topographic factors
K erodibility due to intrinsic soil properties
P effect of soil conservation practice
C erodibility due to land cover

Sediment Supply Index – Revised Universal Soil Loss Equation

Image modified from David Simon



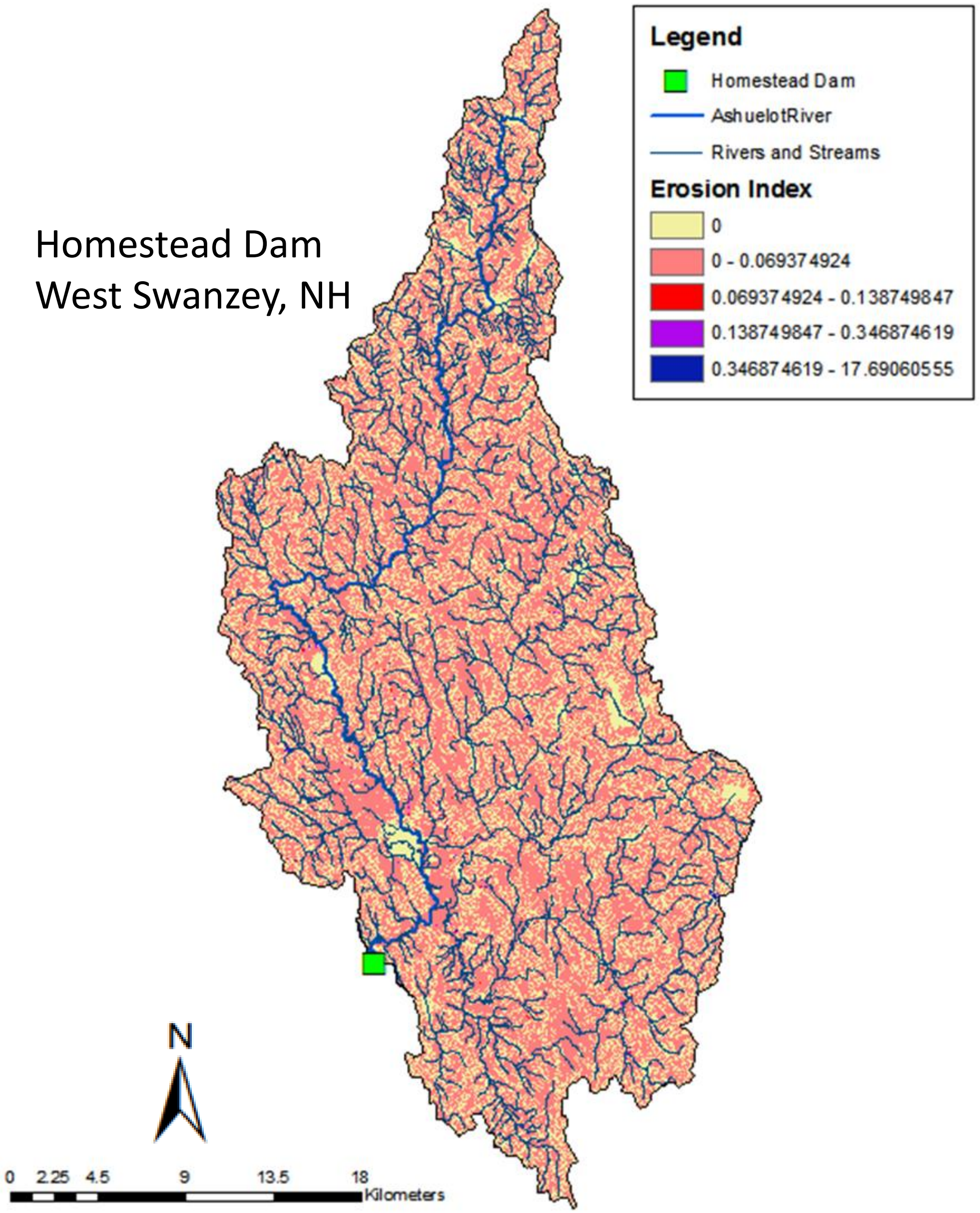
$$Y = \cancelto{1}{R} \times LS \times K \times \cancelto{1}{P} \times C$$

$$Erosion\ Index = LS \times K \times C$$

Y average annual soil loss per unit area
R erodibility due to precipitation
LS erodibility due to topographic factors
K erodibility due to intrinsic soil properties
P soil conservation practice factor
C erodibility due to land cover

Calculating the Erosion Index Using High-Resolution Spatial Data

Homestead Dam
West Swanzey, NH



$$LS_i$$

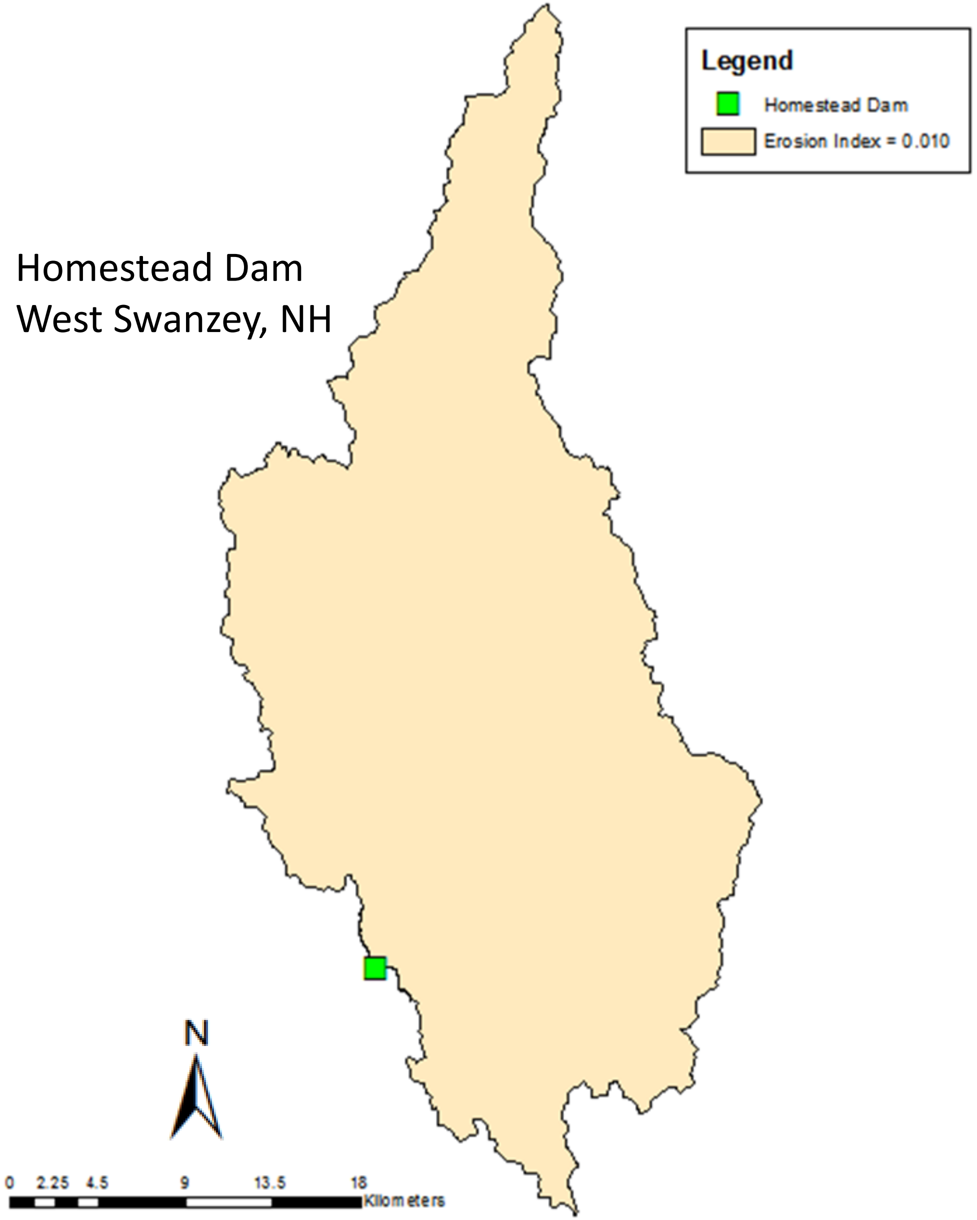
erodibility due to topographic factors

$$Erosion\ Index = \frac{\sum_{i=0}^{n\ cells} Erosion\ Index_i}{A_{watershed}}$$

Relationships between Impounded Sediment and Erosion Index

Calculating the Erosion Index using Watershed Average Data

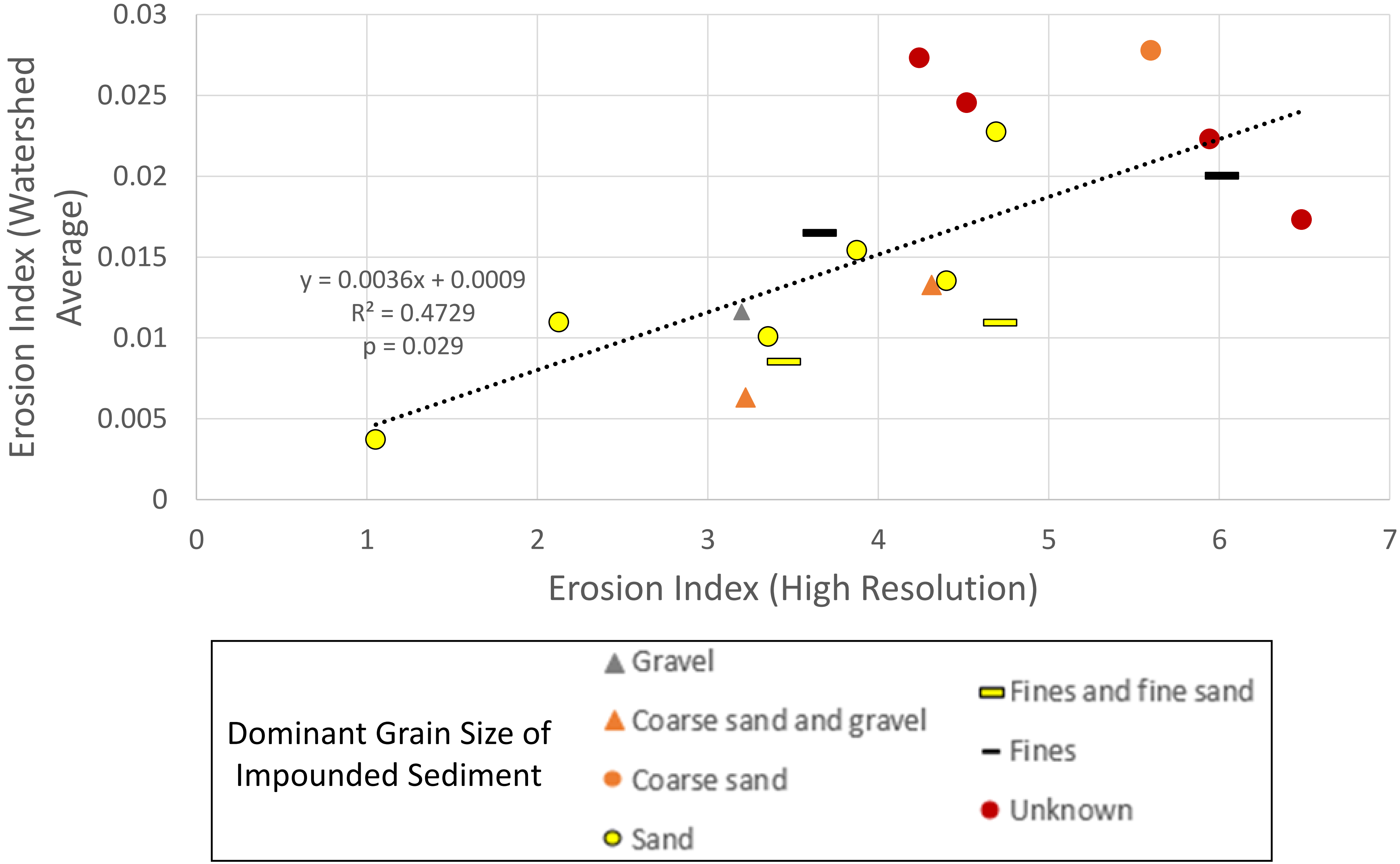
Homestead Dam
West Swanzey, NH



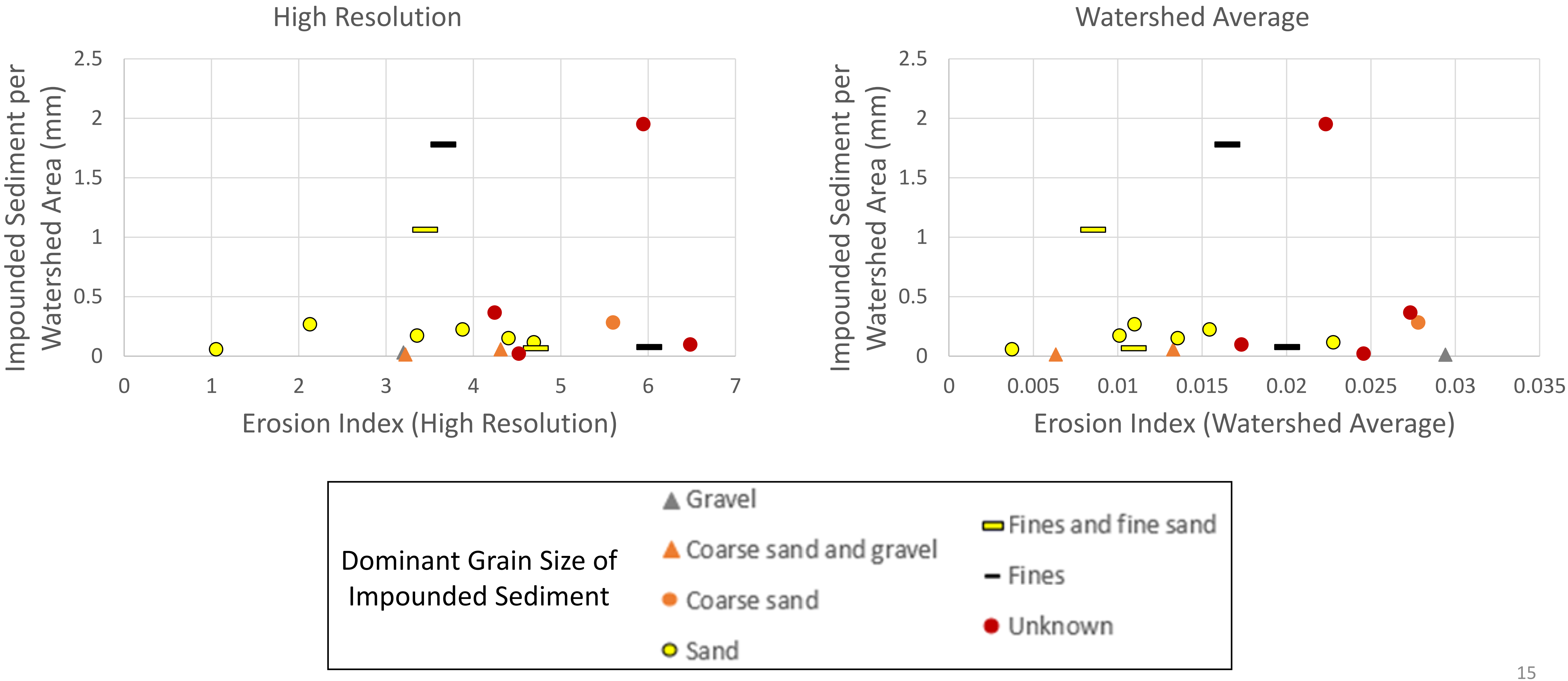
LS

erodibility due to topographic factors

Watershed-Average Agrees with High-Resolution Erosion Index

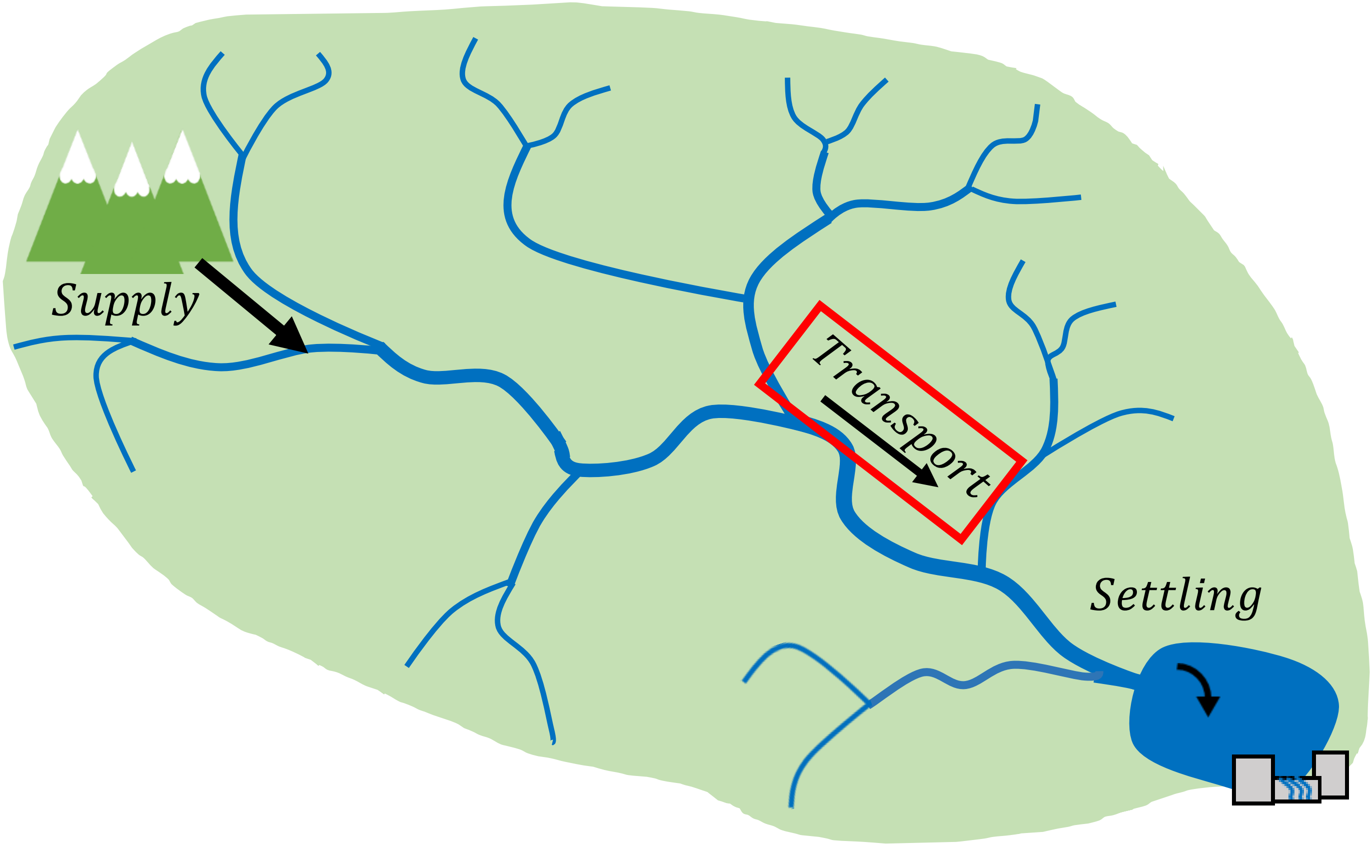


Relationships between Impounded Sediment and Erosion Index



Sediment Transport Proxy – Stream Power

Image modified from David Simon



$$TSP = \gamma Q_{bnk} S$$

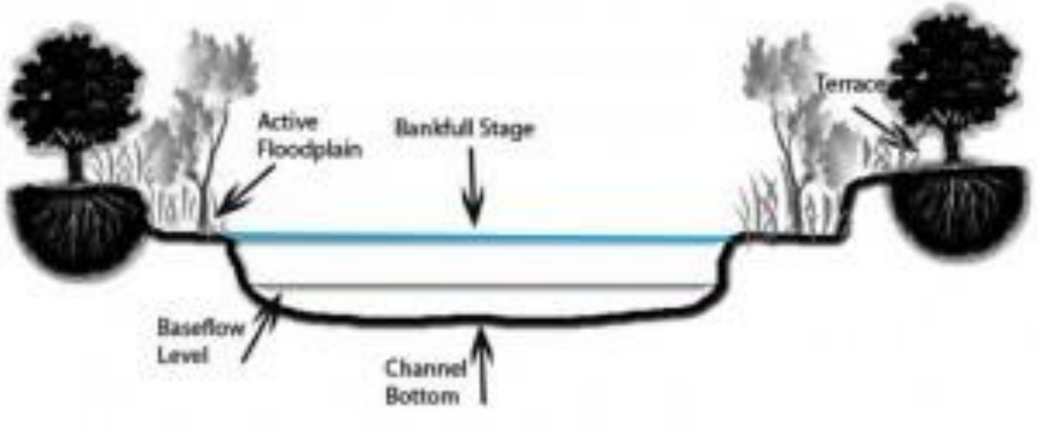
$$SSP = \frac{\gamma Q_{bnk} S}{W_{bnk}}$$

TSP total stream power (kinetic energy of river)
SSP specific stream power (kinetic energy of river per unit width)
γ specific weight of water (gravity constant × water density)
Q_{bnk} river bankfull discharge
S river slope
W_{bnk} river bankfull width

Bankfull Flow in New England

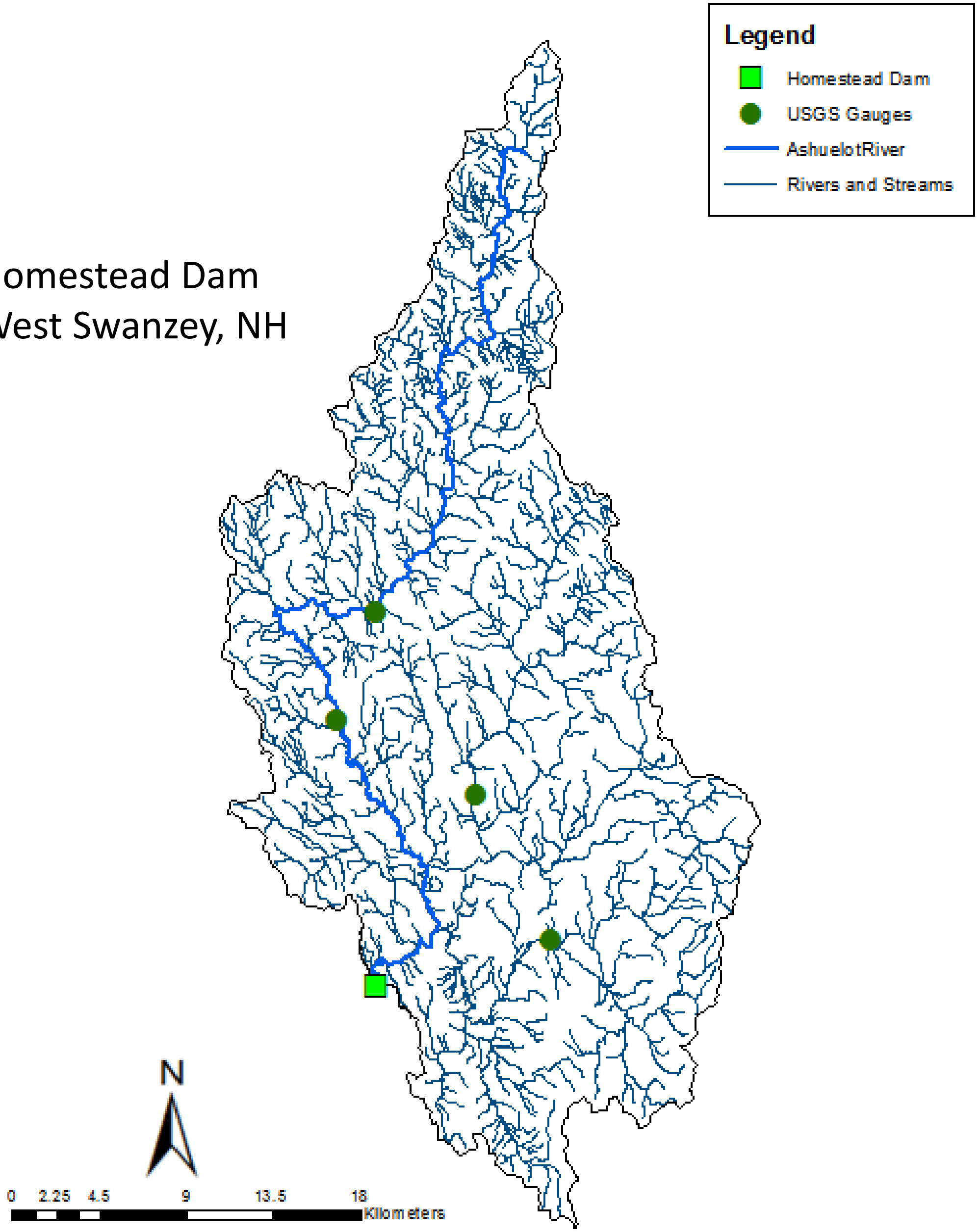
- Averaged over many years, bankfull flow transports the largest amount of sediment
- Bankfull widths can be remotely sensed using high-resolution topography
- Recurrence interval for bankfull discharges ≈ 1.5 years (Bent and Waite, 2013; Milone & MacBroom, Inc., 2007; Vermont Department of Environmental Conservation, 2007)

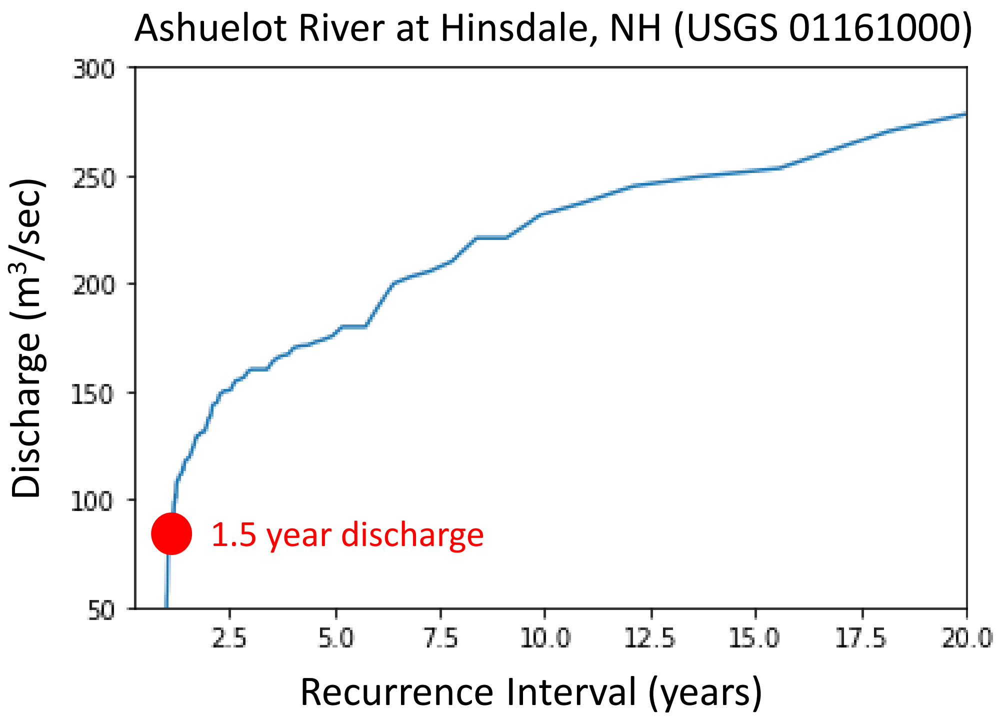

Stony Clove Creek, Ulster County, NY



Calculating Bankfull Discharge Using USGS Gauges

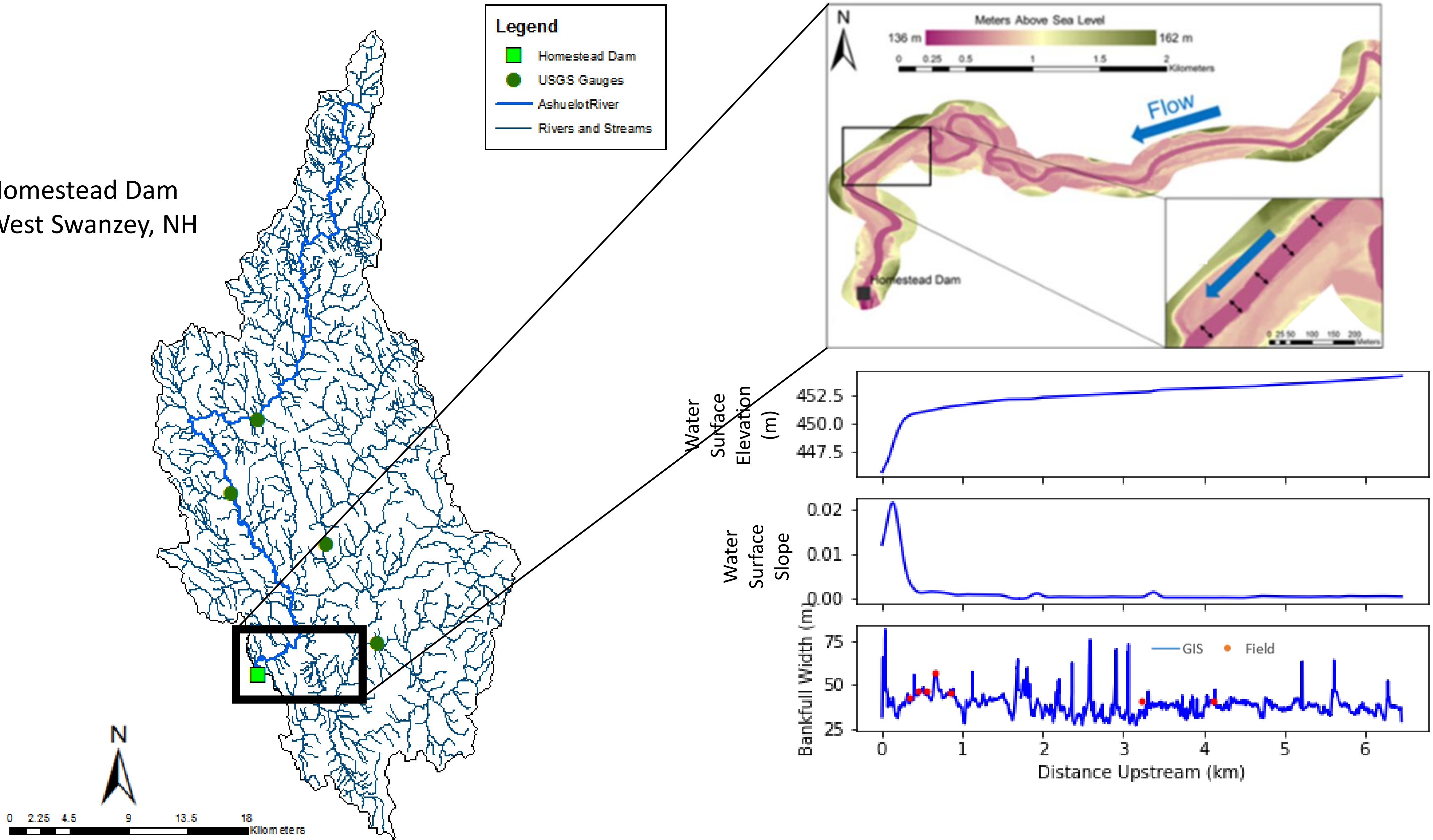
Homestead Dam
West Swanzey, NH



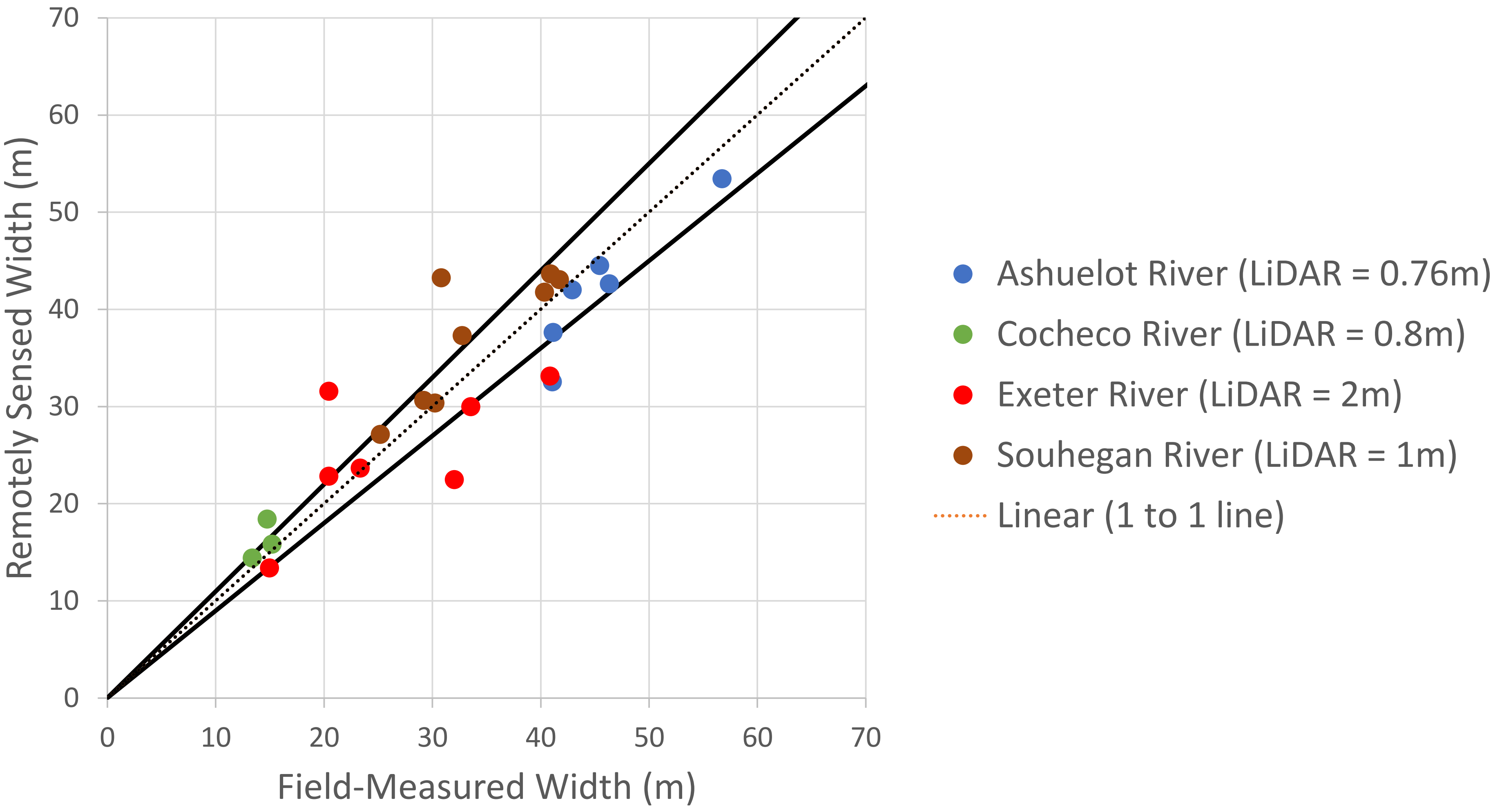


Calculating Bankfull Width and Water Surface Slope

Homestead Dam
West Swanzey, NH

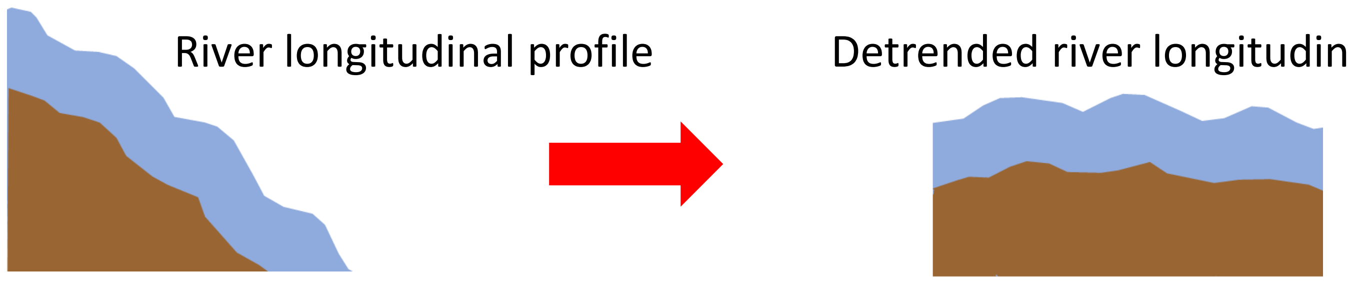


Remotely Sensed Widths Agree with Field Measurements

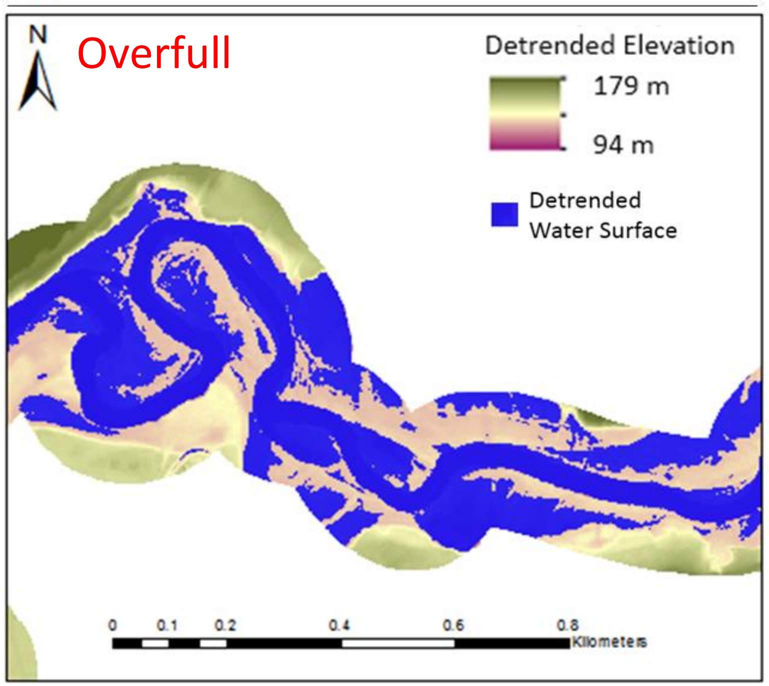


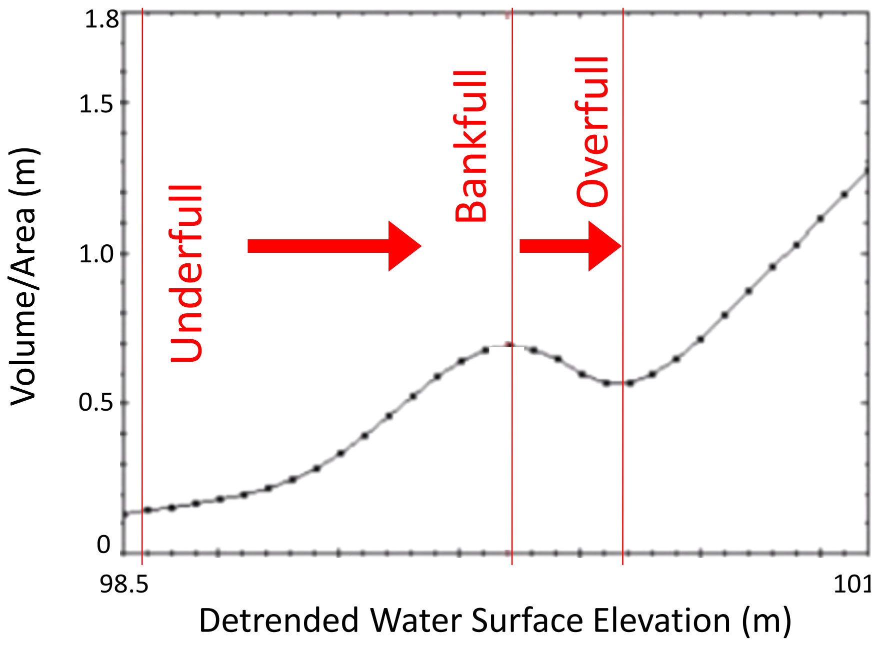
Methods for Calculating Bankfull Width (River Bathymetry Toolkit; McKean, 2014)

1. River slope eliminated creating flat river topography



2. Flat river topography filled just prior to water spilling out onto floodplain





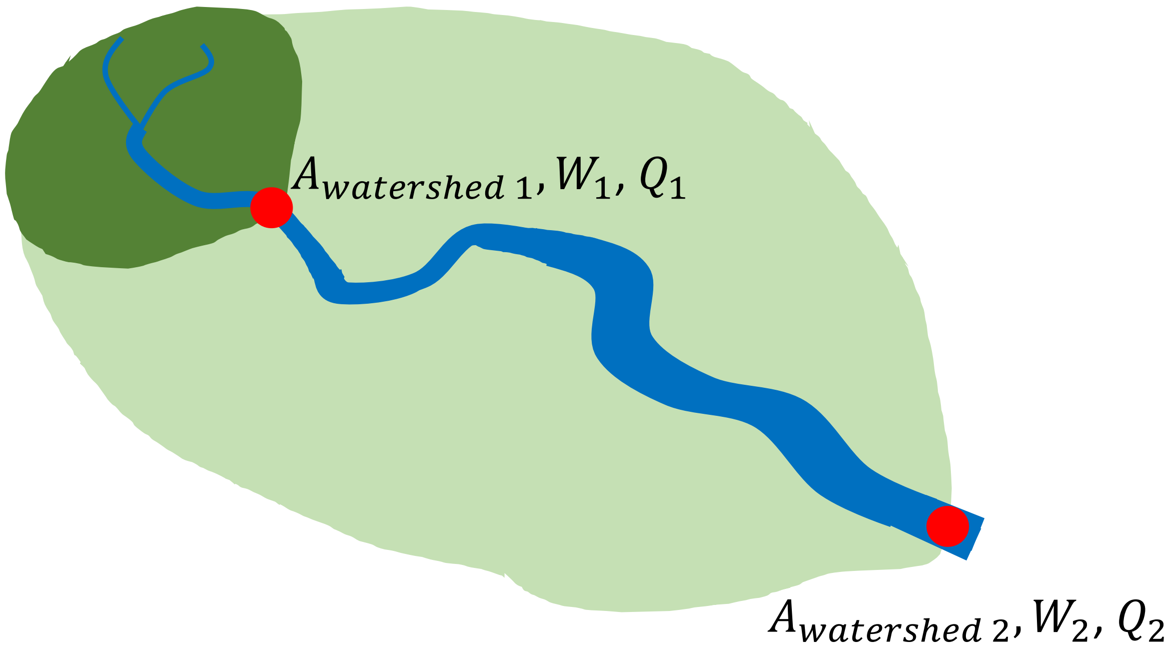
Hydraulic Geometry

- Equations that describe relationship between watershed area ($A_{watershed}$) and bankfull river width (W_{bnk}) and discharge (Q_{bnk})

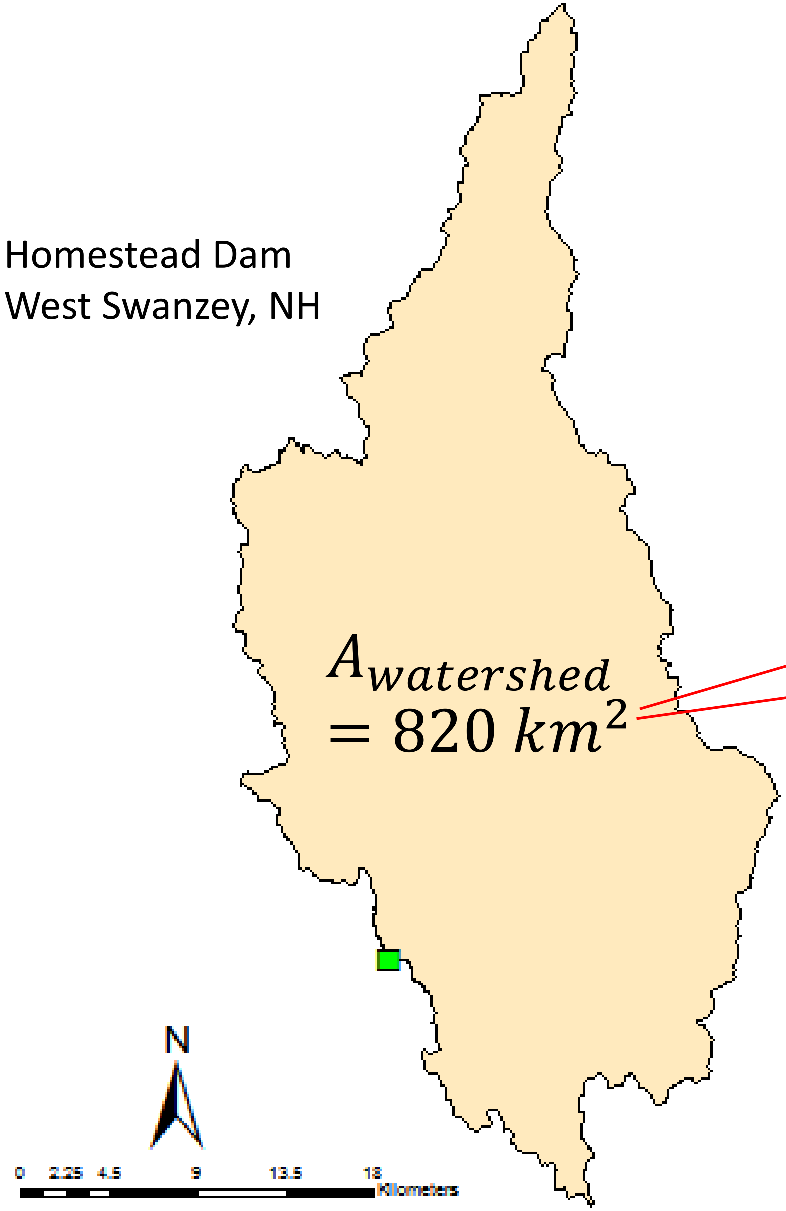
$$Q_{bnk} = gA_{watershed}^{h}$$

$$W_{bnk} = cA_{watershed}^{f}$$

- c, f, g and h hydraulic geometry constants whose magnitude depends on local geology and topography



Calculating Stream Power Using Watershed-Average Data



Approximate water surface slope (S) as average watershed slope (NHDV2+)

Use hydraulic geometry to obtain bankfull discharge/width

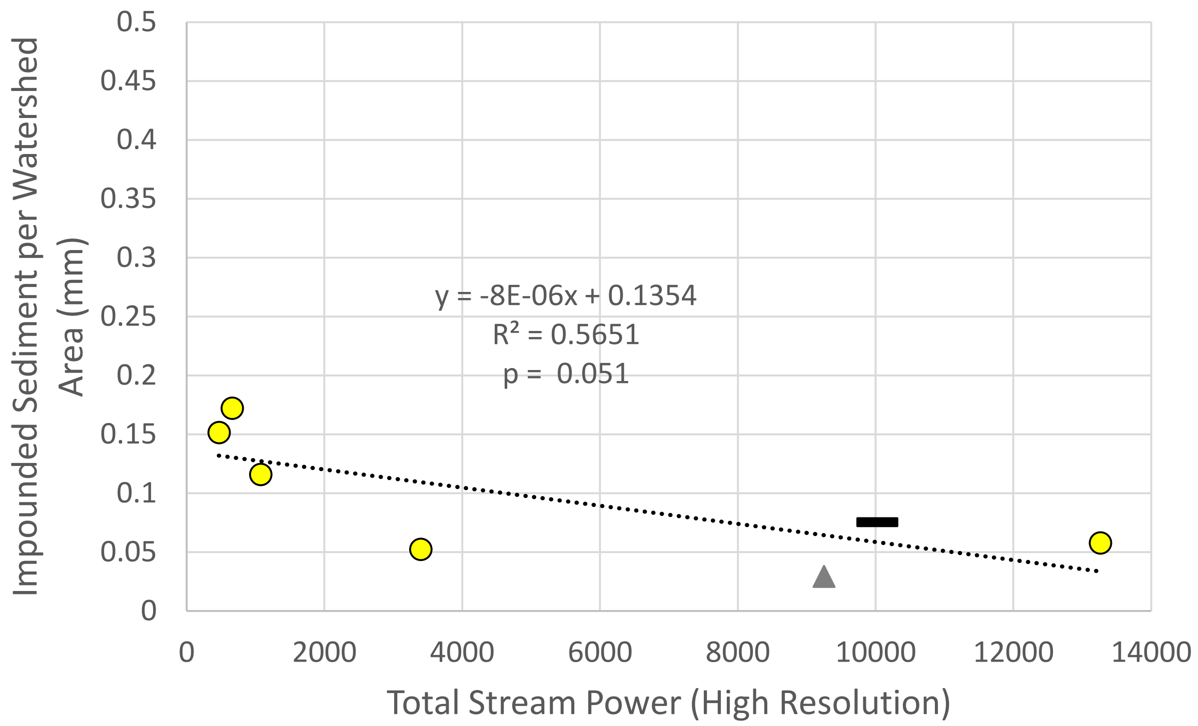
$$Q_{bnk} = gA_{watershed}^{h} \qquad W_{bnk} = cA_{watershed}^{f}$$

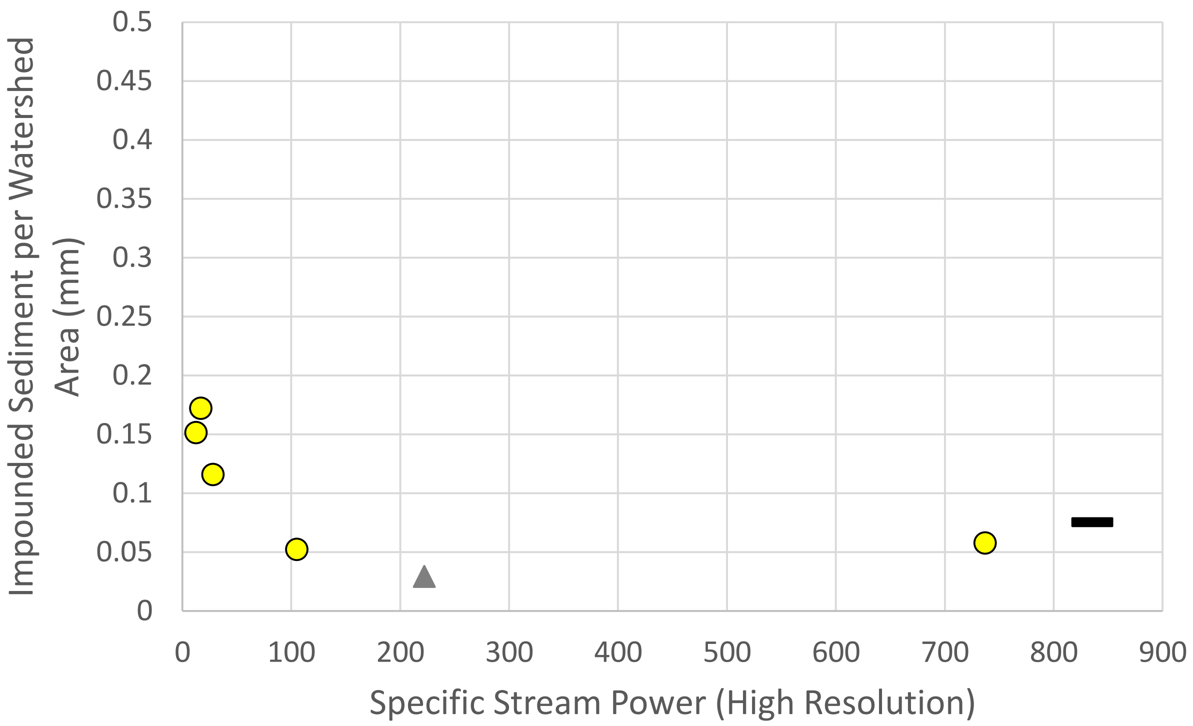
Stream power calculations

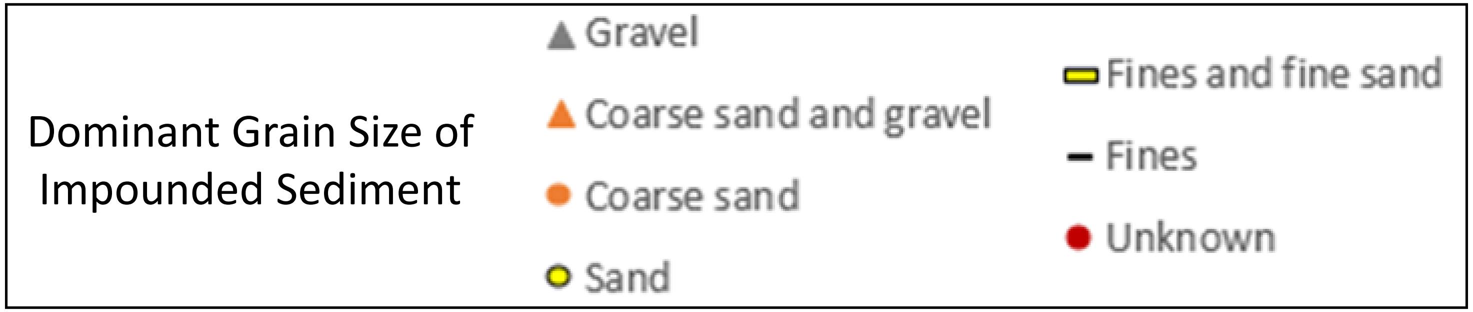
$$TSP = \gamma Q_{bnk} S \qquad SSP = \frac{\gamma Q_{bnk} S}{W_{bnk}}$$

$$TSP = 3.1 \times 10^5\ Watts/m^2 \qquad SSP = 4.9 \times 10^3\ Watts/m^2$$

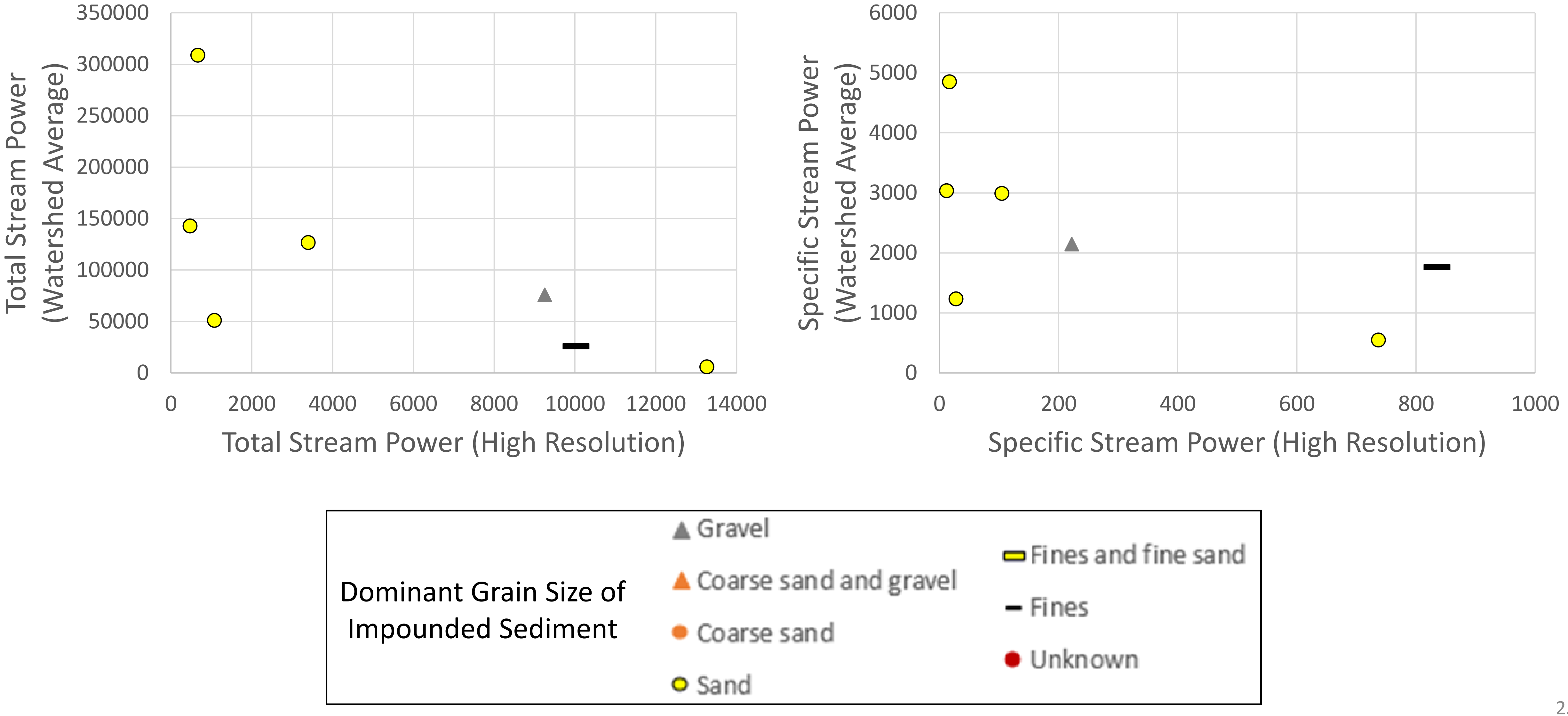
Relationships between Impounded Sediment and Stream Power



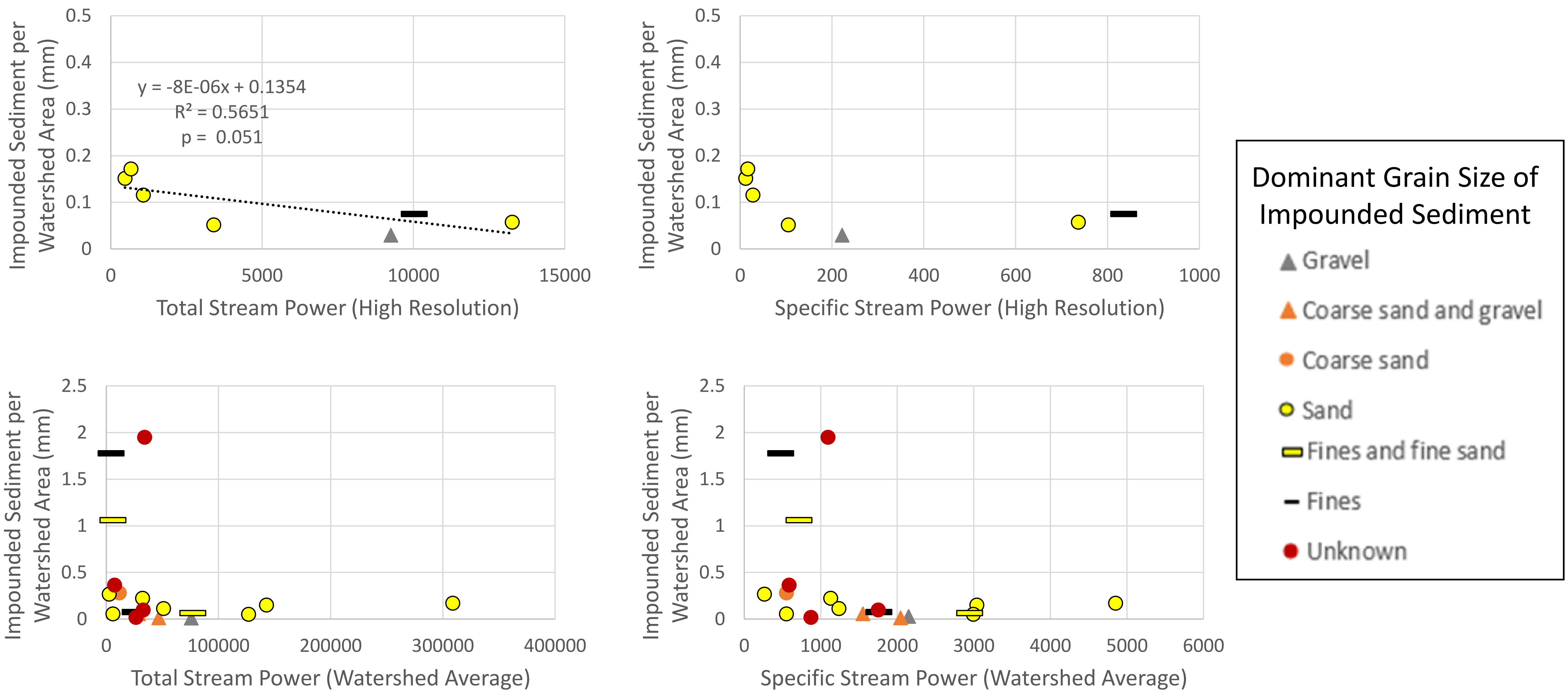




Watershed-Average and High-Resolution Stream Power

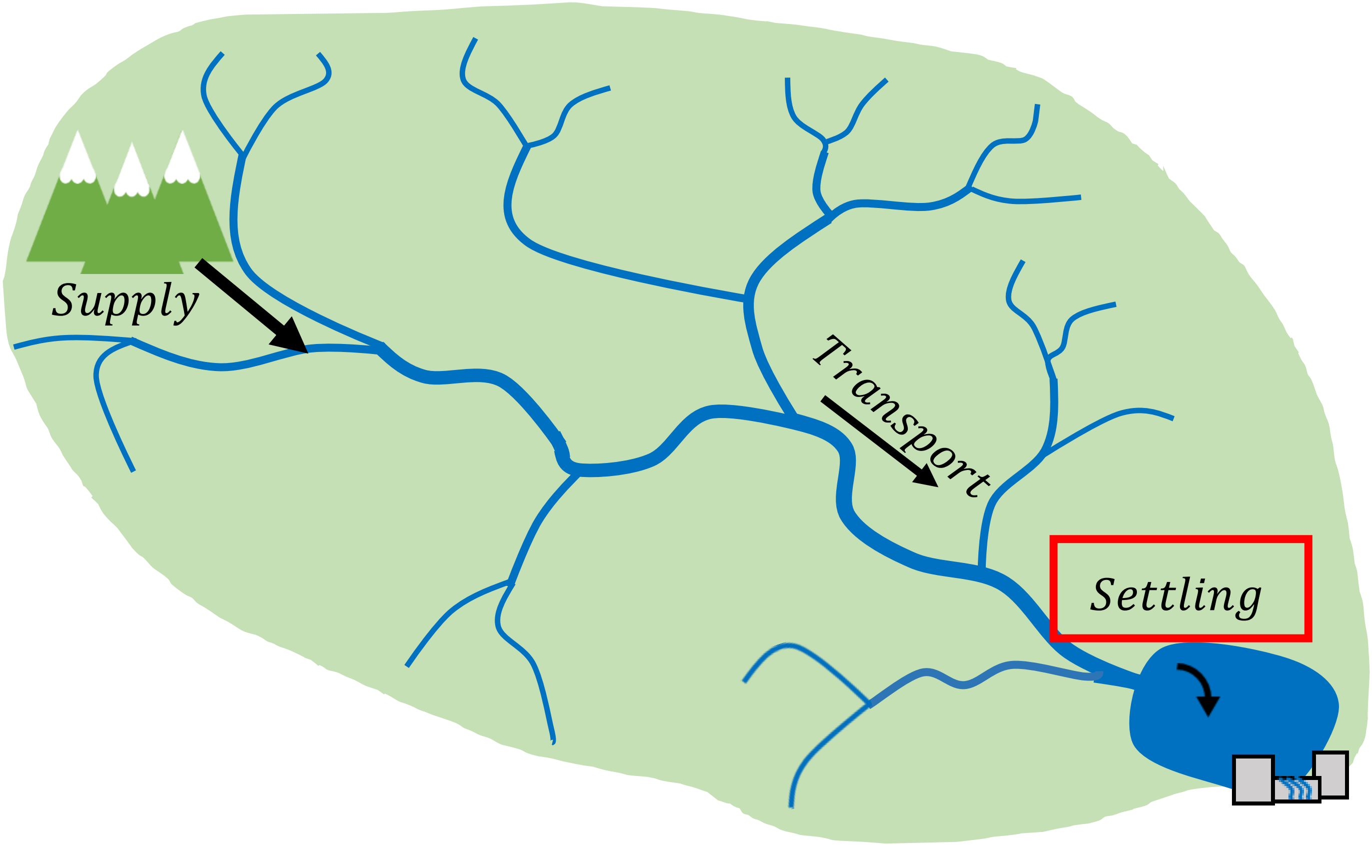


Relationships between Impounded Sediment and Stream Power



Sediment Settling Proxies – Impoundment Geometry

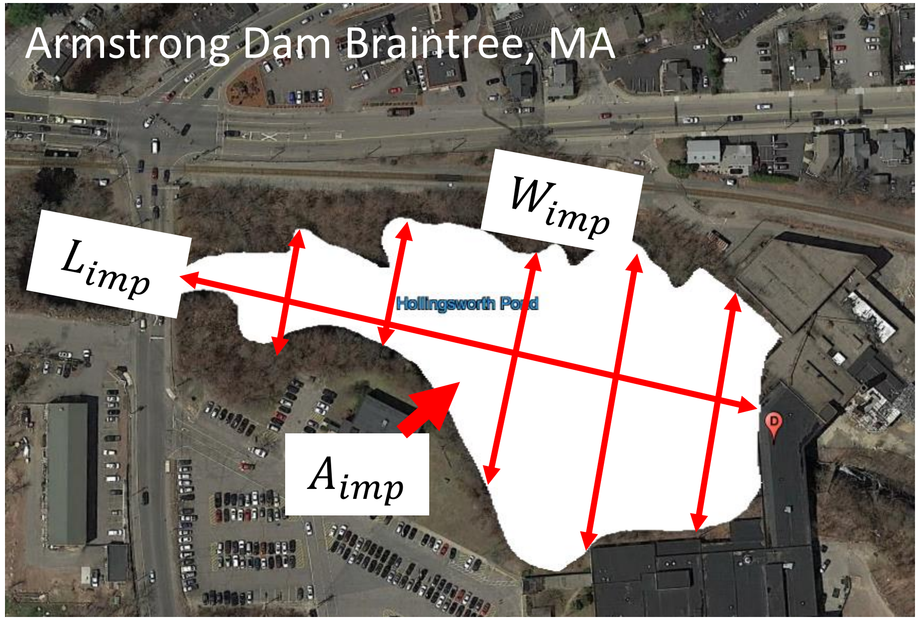
Image modified from David Simon



- Impoundment surface area (A_{imp})
- Impoundment aspect ratio $\left(\frac{W_{imp}}{L_{imp}}\right)$

Sediment Settling Proxies – Impoundment Geometry

Ponded Impoundment



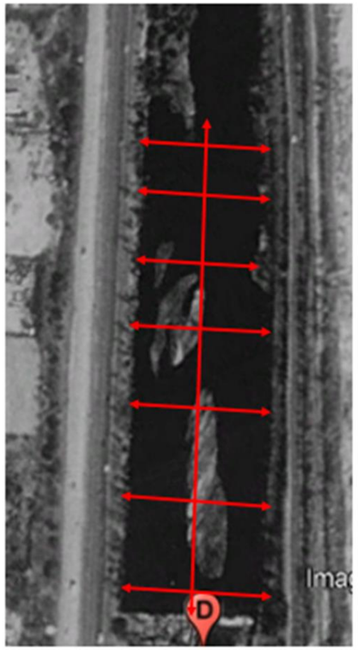
Impoundment surface area:

$$A_{imp} = 0.016\ km^2$$

Impoundment aspect ratio:

$$\frac{\overline{W_{imp}}}{L_{imp}} = 0.27$$

Run of River Impoundment



Anaconda Dam, Waterbury, CT

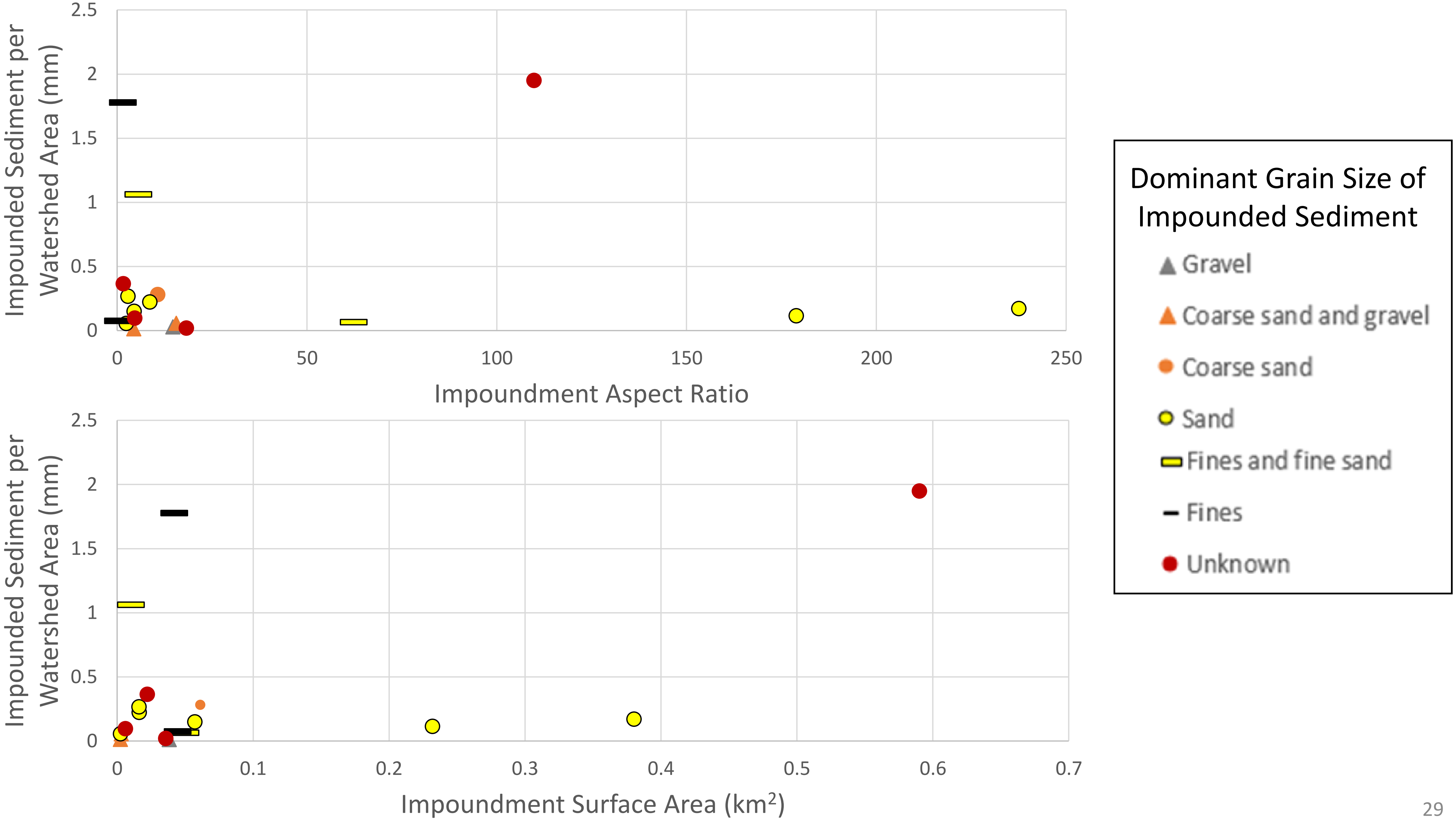
Impoundment surface area:

$$A_{imp} = 0.069\ km^2$$

Impoundment aspect ratio:

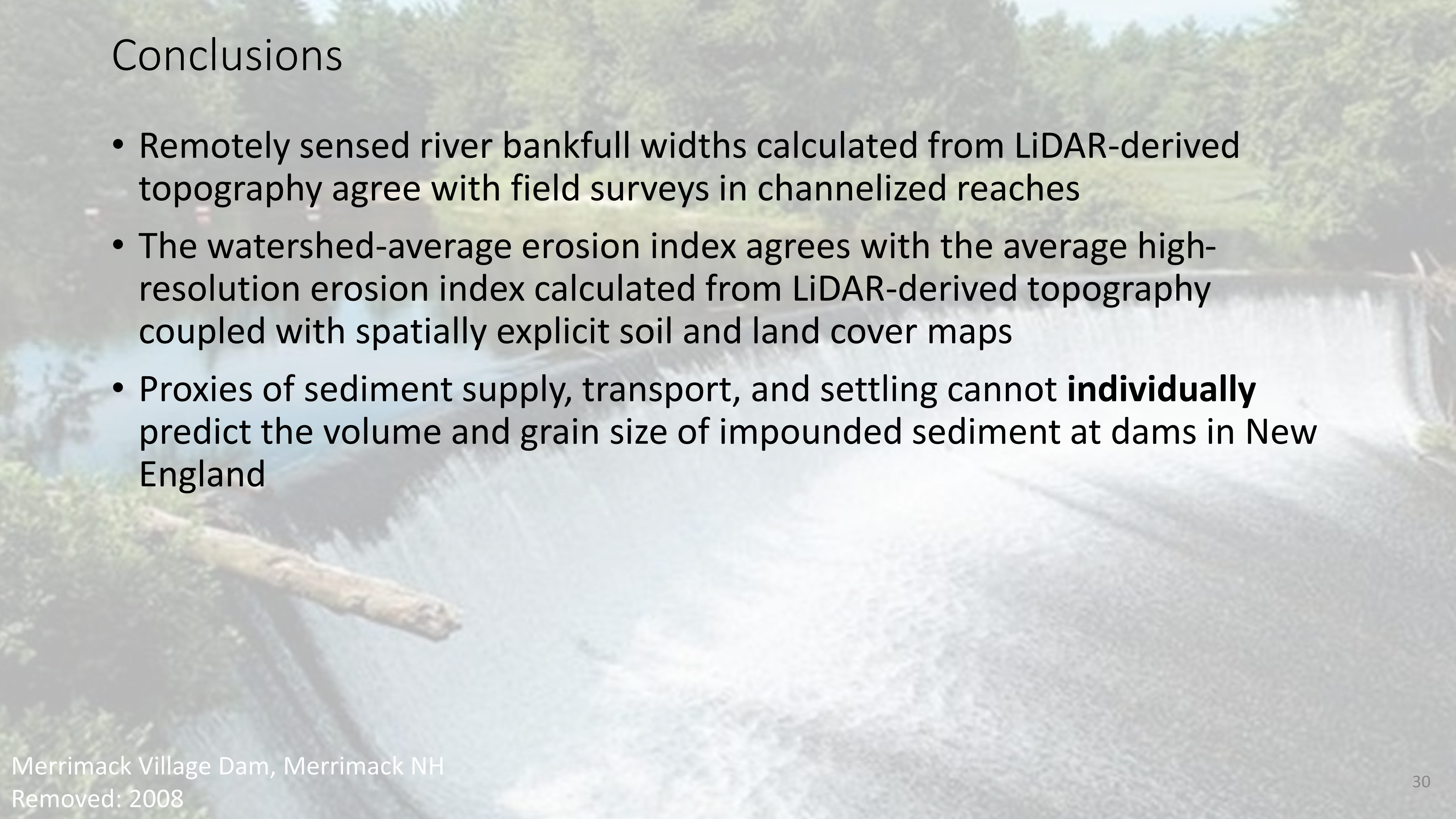
$$\frac{\overline{W_{imp}}}{L_{imp}} = 0.094$$

Relationships between Impounded Sediment and Impoundment Geometry



Conclusions

- Remotely sensed river bankfull widths calculated from LiDAR-derived topography agree with field surveys in channelized reaches
- The watershed-average erosion index agrees with the average high-resolution erosion index calculated from LiDAR-derived topography coupled with spatially explicit soil and land cover maps
- Proxies of sediment supply, transport, and settling cannot **individually** predict the volume and grain size of impounded sediment at dams in New England



Merrimack Village Dam, Merrimack NH
Removed: 2008

Future Research

- Perform multivariable regression analysis to combine proxies of sediment supply, transport and settling to predict the volume and grain size of impounded sediment
- Increase sample size by identifying additional dams where impounded sediment characteristics have been surveyed and upstream high-resolution datasets are available
- Use multivariable regression relationships to estimate impounded sediment characteristics at additional dams in New England where impounded sediment surveys are not available, and use results to conduct a dam removal tradeoff analysis

Merrimack Village Dam, Merrimack NH
Removed: 2008

Dam Removal Tradeoff Analysis

Dam Safety		Fish Passage Gains		Sediment Volume		Grain Size		Dam Removal Priority Index	
5: Significant hazard	↑	5: Greatly inhibits passage	↑	5: Low volume	↑	5: Gravel	↑	20: High priority for removal	↑
3: High hazard	↕	3: Moderately inhibits passage	↕	3: Moderate volume	↕	3: Sand	↕		↕
1: Low hazard	↓	1: Mildly inhibits passage	↓	1: High volume	↓	1: Fine-grained sediment	↓	4: Low priority for removal	↓

Can easily add additional attributes to the dam removal priority index (assuming comprehensive databases exist)

Preliminary Dam Removal Tradeoff Analysis

Dam Name	Location	Dam Safety	Fish Passage Gains	Sediment Volume	Grain Size	Dam Removal Priority Index
Neponset River Dam - Hyde Park	Milton, MA	5	4	4		16
Ipswich River Dam	Middleton, MA	5	5	2	4	16
Marshfield-8 Dam	Marshfield, VT			5	5	16
Perryville Pond Dam	Rehoboth, MA	5	5	2	3	15
International Paper Co. Dam	Gill, MA			4	5	15
Anaconda Dam	Waterbury, CT			3	5	14
Briggsville Dam	Clarksburg, MA			4		13
Rattlesnake Brook Dam	Freetown, MA			4	3	13
Pin Shop Pond Dam	Watertown, CT	3	3	3		12
Becket Silk Mill Dam	Becket, MA		1	5	3	12
Dufresne Dam	Manchester, VT			5	1	12
Ben Smith Dam	Maynard, MA	5	2	1		11
East Burke (Lumber Co.)	Burke, VT	1	5	3	2	11
Heminway Pond Dam	Watertown, CT		4	2	1	10
Pawtuxet Falls Dam	Cranston and Warwick, RI			1	3	10
Norwich Reservoir	Norwich,VT	1	3	3	2	9
Merrimack Village Dam	Merrimack, NH		1	1	3	8
Goldman Dam	Milford, NH	1	2	2	3	8
Homestead Woolen Mill Dam	Swanzey, NH		1	1	3	8

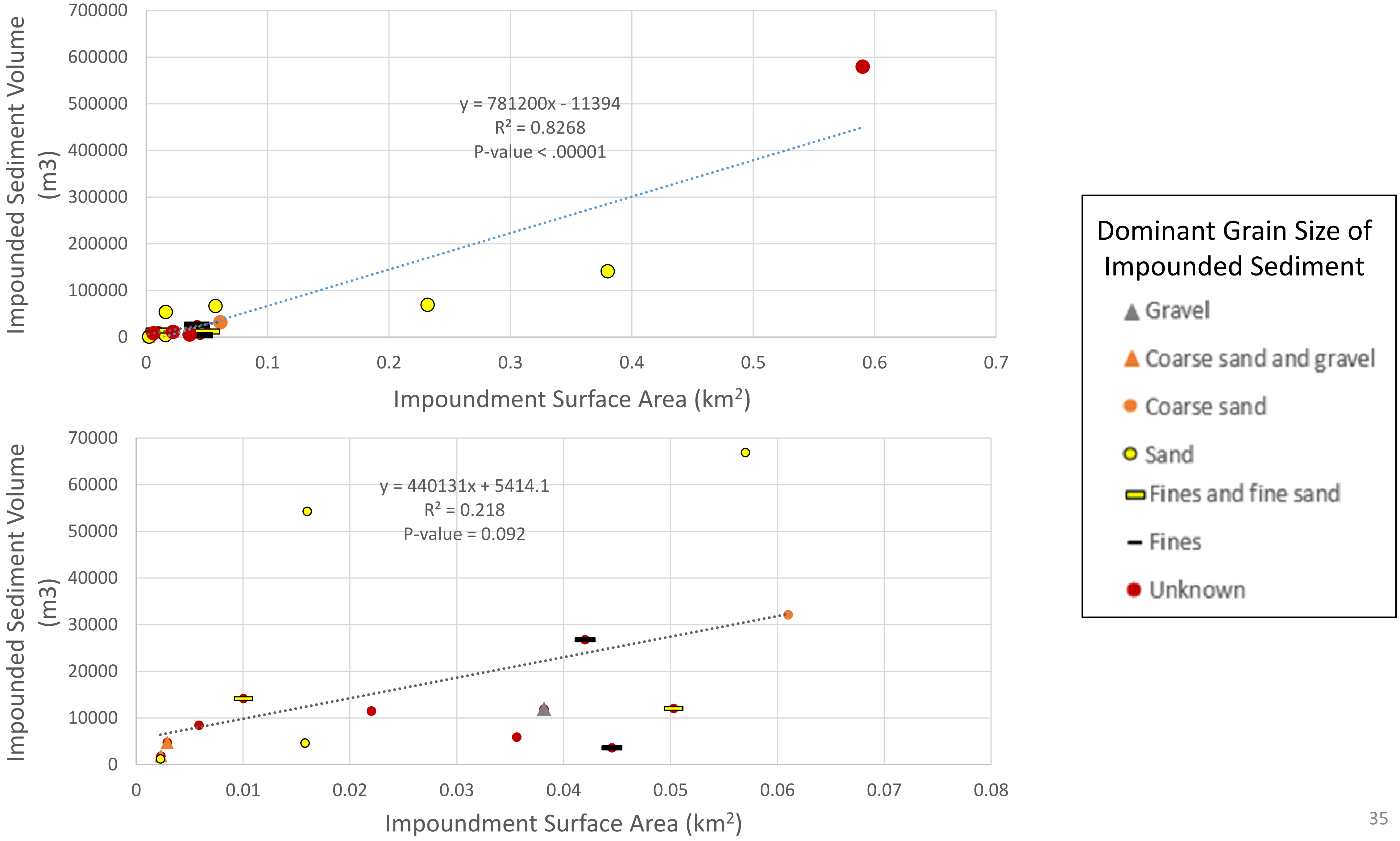
Grey indicates missing data; priority assumed to be 3 when calculating preliminary total index

Estimated impounded sediment characteristics from regression relationships could be used to conduct a removal tradeoff analysis of dams across New England

Questions?

Christian Olsen, cto1003@wildcats.unh.edu

Merrimack Village Dam, Merrimack NH
Removed: 2008



Impounded Sediment Volume (m3)
700000
600000
500000
400000
300000
200000
100000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
y = 781200x - 11394
R² = 0.8268
P-value < .00001
Impoundment Surface Area (km²)
Impounded Sediment Volume (m3)
70000
60000
50000
40000
30000
20000
10000
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
y = 440131x + 5414.1
R² = 0.218
P-value = 0.092
Impoundment Surface Area (km²)
Dominant Grain Size of Impounded Sediment
Gravel
Coarse sand and gravel
Coarse sand
Sand
Fines and fine sand
Fines
Unknown

Best Available and Broadly Applicable Data

Metric	Parameter	Best Available Data	Broadly Applicable Data
Sediment Supply (Watershed Erosion)	Soil erodibility of gravelly, sandy, and fine watershed soils (K factor)	Fine resolution soil survey data (SSURGO soil database)	Coarse resolution soil survey data (STATSGO soil database)
	Slope erodibility (LS factor)	High resolution DEMs (LiDAR)	Average watershed slope
	Land cover type erodibility (P factor)	Spatially distributed land cover (National Land Cover Database)	Watershed-scale lumped land cover data (Dam Databases)
Sediment Transport (Stream Power)	Bankfull discharge	Stream gauges (USGS)	Hydraulic geometry
	Bankfull width	High-resolution, ground truthed remotely sensed data (LiDAR)	Hydraulic geometry
	Slope	Remotely sensed slope using fine resolution DEMs (LiDAR)	Average watershed slope
Dam Trap Efficiency	Impoundment surface area	Aerial and satellite imagery	Aerial and satellite imagery (Dam Databases)

High-Resolution Topography

River and impoundment structure upstream of Anaconda Dam