Floodplain/streambank modulation of river loads of sediment and nutrients, from reaches to watersheds to regions

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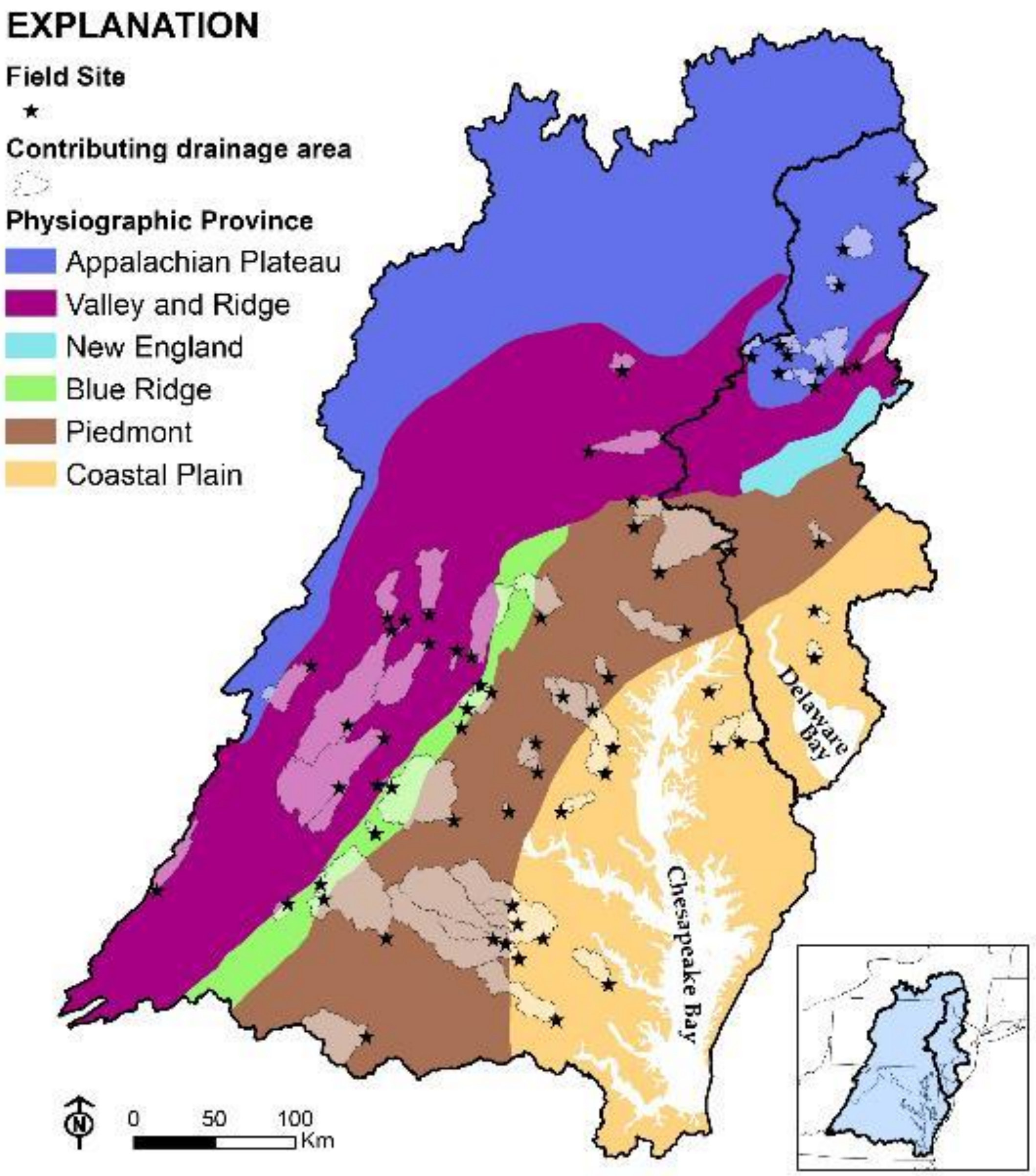
USGS Chesapeake and Delaware Floodplain Network: network design

Long-term streambank and floodplain characteristics and sediment and associated nutrient loss/gain were measured at <u>68 reaches</u> across U.S. Mid-Atlantic

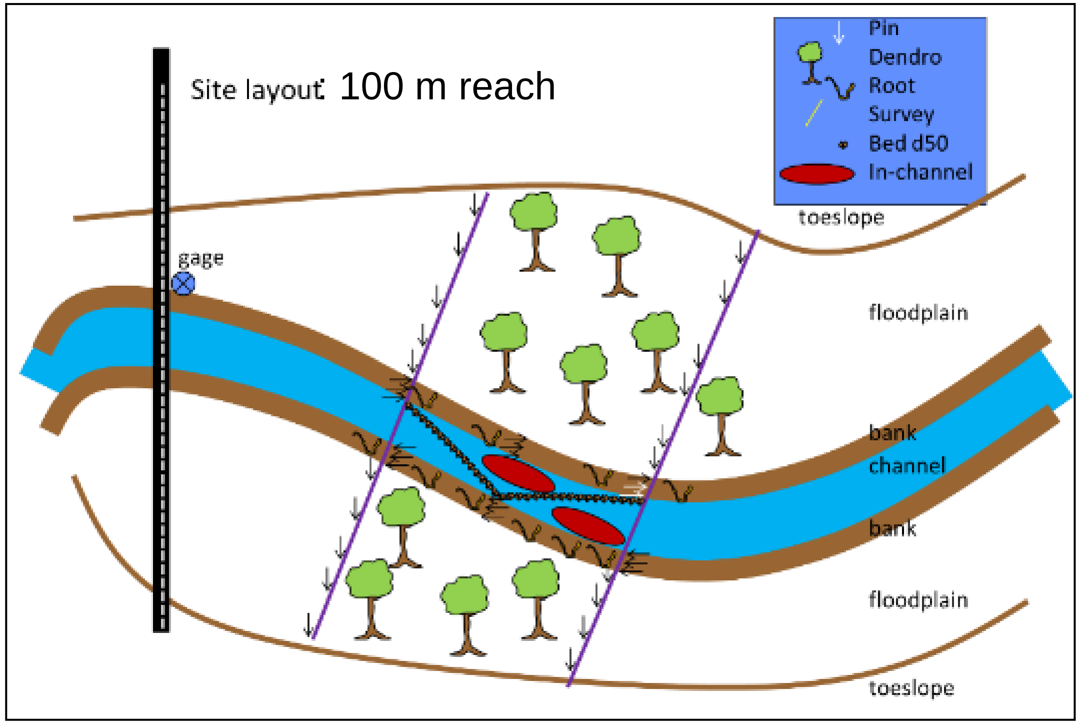
These sites are <u>representative</u> of regional variability in watershed drainage area, geology, topography, soils, hydrology, and land use

<u>Site selection</u>:

- Mixture of USGS NTN load gages and ungaged reaches
- ‘Unmanaged’ floodplain land use (with woody vegetation)
- Unchannelized
- Landowner permission



USGS Chesapeake and Delaware Floodplain Network: measurements at 68 reaches



Stream valley x-section surveying:
136 x-sections

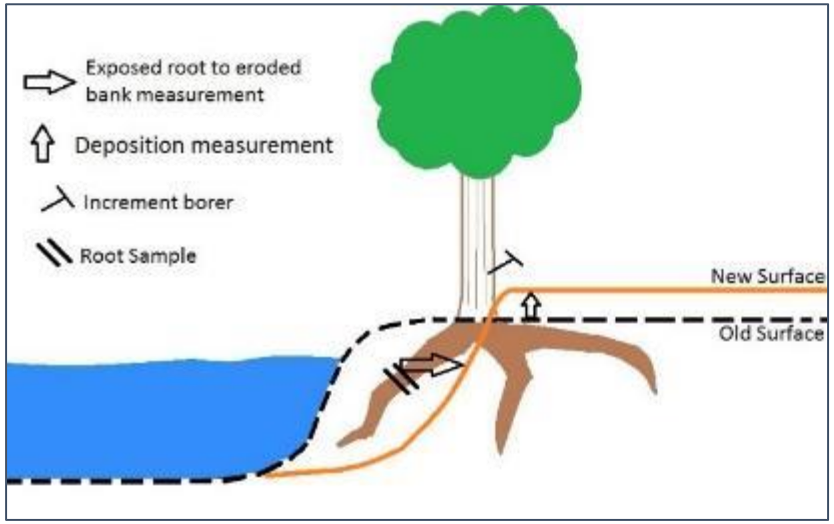
Floodplain tree coring:
667 floodplain tree cores

Bank root:
457 bank root samples

Floodplain sed coring (5 cm deep):
376 floodplain samples

Bank sed coring (5 cm deep):
541 bank samples

Dendrogeomorphic fluxes



Root analysis to determine years since exposure

Geomorphic measurements:

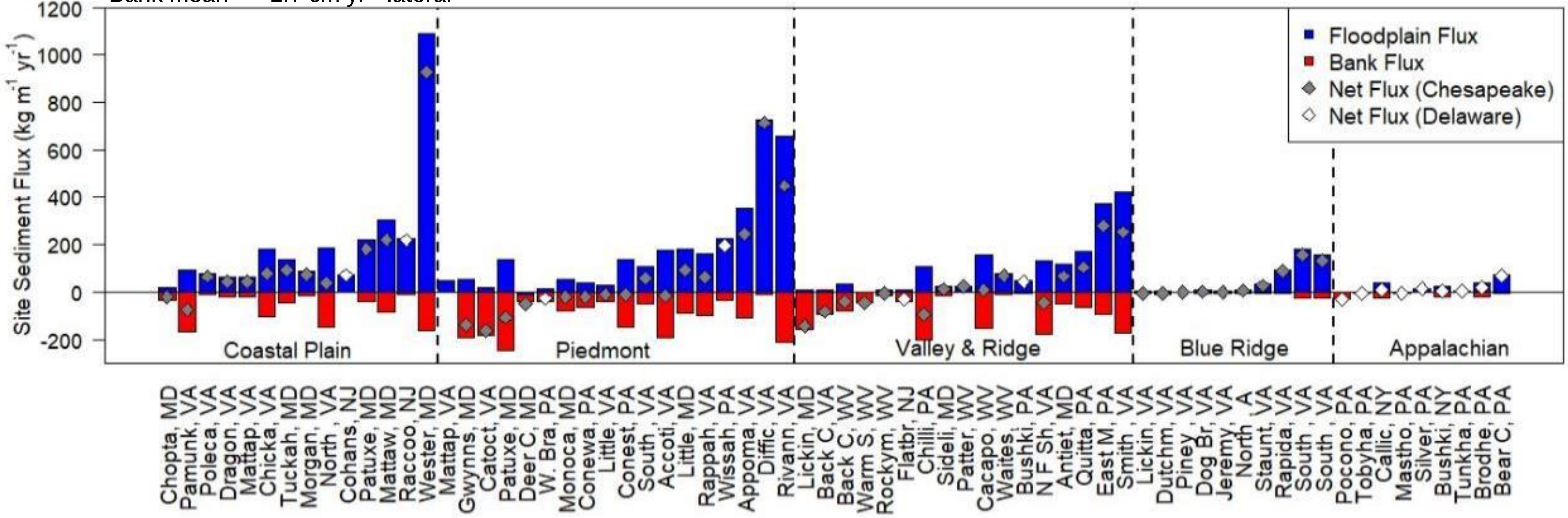
Active (~2 yr) floodplain width
Bank height
Channel width
Lateral and vertical change (cm/yr)
% eroding bank
Adjusted lateral erosion (cm/yr)

Sediment characteristics:

Bulk density (g/cm3)
Bulk density <2 mm (g/cm3)
Bulk density <1 mm (g/cm3)
% organic
% mineral
% carbonate
Total OC (%)
Total N (%)
Total P (%)
Total Ca (mg/g)
Total Na (mg/g)
Total Mg (mg/g)
Total K (mg/g)
Total Al (mg/g)
Total Fe (mg/g)
Total Ti (mg/g)
Particle size: mean (um)
Particle size: d50 (um)
Particle size: %<63 um

USGS Chesapeake and Delaware Floodplain Network: long-term bank and floodplain fluxes

FP mean = +0.3 cm yr^{-1} vertical
Bank mean = -1.7 cm yr^{-1} lateral



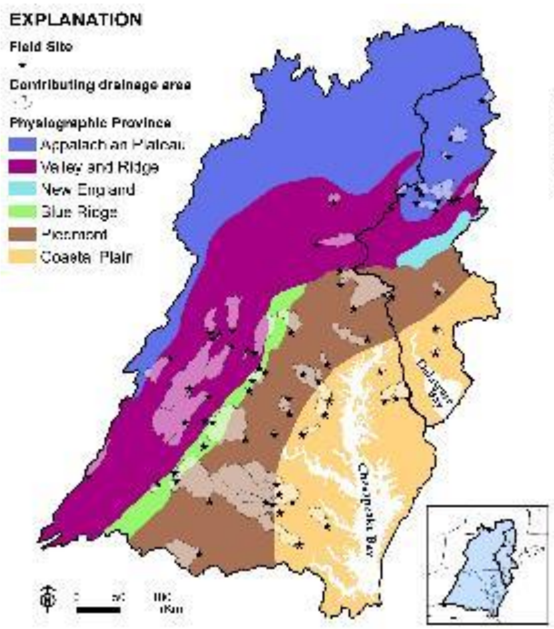
<u>Mean ages of trees:</u>
floodplain = 51 yr,
bank = 17 yr exposed

<u>Bank flux =</u>
lateral change rate * bulk density * bank height * 2 * %eroding

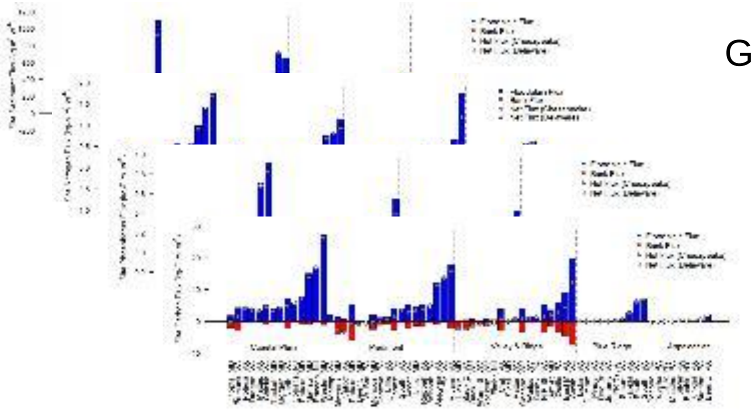
<u>Floodplain flux =</u>
vertical change rate * bulk density * total floodplain width

USGS Chesapeake and Delaware Floodplain Network: approach

Measure



Analyze



Model
(Random Forest)

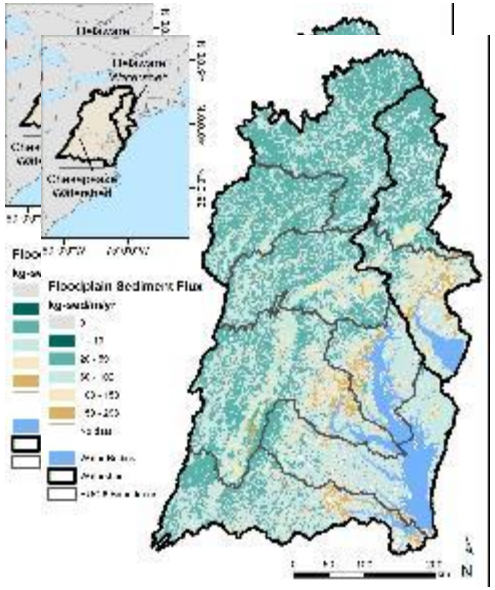
GIS reach-scale geomorphometry ("shape")
Floodplain width, bank height, channel width, …

Random Forests regressions

GIS upstream watershed attributes
Land use, hydrology, soils, topography

GIS upstream watershed attributes
FUTURE Land use, hydrology, soils, topography

Predict
(99,664 NHDPlusV2 reaches)



Predictions:

Floodplain sediment flux
Floodplain fine sediment flux
Floodplain sediment-N flux
Floodplain sediment-P flux
Floodplain sediment-C flux
Floodplain change m^2

Streambank sediment flux
Streambank fine sediment flux
Streambank sediment-N flux
Streambank sediment-P flux
Streambank sediment-C flux
Streambank lateral erosion rate
Streambank change m^2

Streambed d50
Streambed fine sediment cover
Streambed fine+sand cover

Random Forest regressions' predictor variables tested

FACET Geomorphometry (Hopkins et al. 2020):

STREAM SLOPE (%)
STREAM SINUOSITY
BANK HEIGHT (m)
CHANNEL WIDTH (m)
FLOODPLAIN WIDTH (m)
BANK ANGLE (deg)
CHANNEL WIDTH / BANK HEIGHT
CHANNEL WIDTH / FLOODPLAIN WIDTH
FLOODPLAIN WIDTH / BANK HEIGHT

+

Watershed Attributes (Wieczorek et al. 2018):

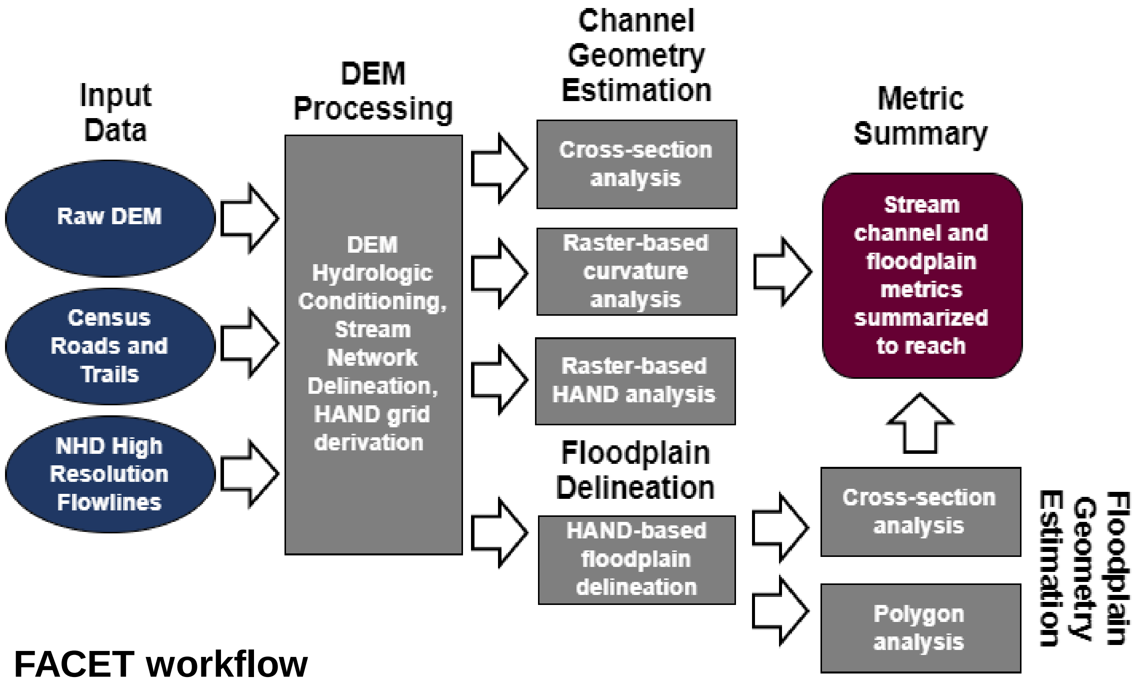
BASIN_AREA	drainage area (km^2)
TWI	topographic wetness index (ln m)
KFACT	erodibility factor
NO200AVE	soil < 74 μm (%)
OLSON_S	rock sulfur content (%)
OLSON_FE	rock iron content (%)
BFI	base flow index (%)
WB5100_ANN	1951-2000 average annual runoff (mm)
IEOF	Horton overland flow (%)
NDAMS2013	# of dams
NLCD2011_21	developed open space (%)
NLCD2011_22+23+24	developed low+med+high intensity (%)
NLCD2011_31	barren land (%)
NLCD2011_41+42+43+52	forest + shrub/scrub (%)
NLCD2011_71+81	grassland + pasture/hay (%)
NLCD2011_82	cultivated crops (%)
NLCD2011_90+95	woody + herbaceous wetland (%)

→ Choose best model for each prediction metric:
1) Watershed attributes; or 2) Geomorphometry + Watershed attributes (if available)

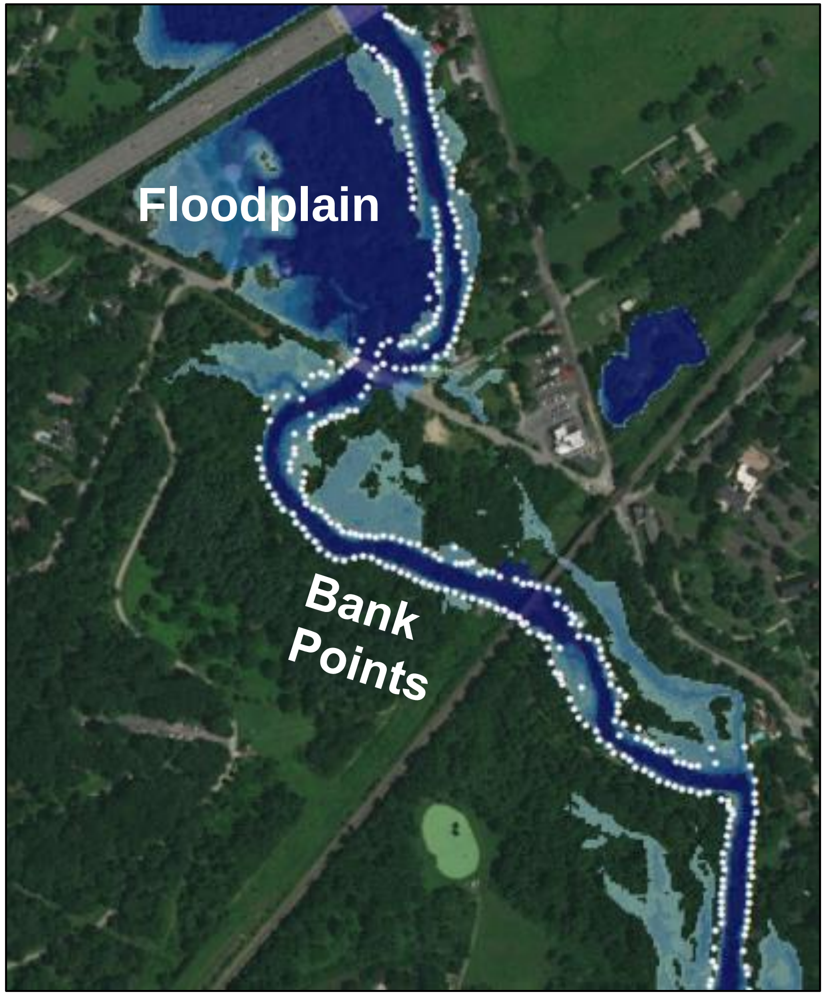
What is FACET?

Automated fine-scale geomorphometry

- Open source Python tool
- Hydrologic conditioning of DEM
- Delineates floodplain & stream network
- Calculating channel and floodplain metrics
- **Code available at code.usgs.gov/water/facet**

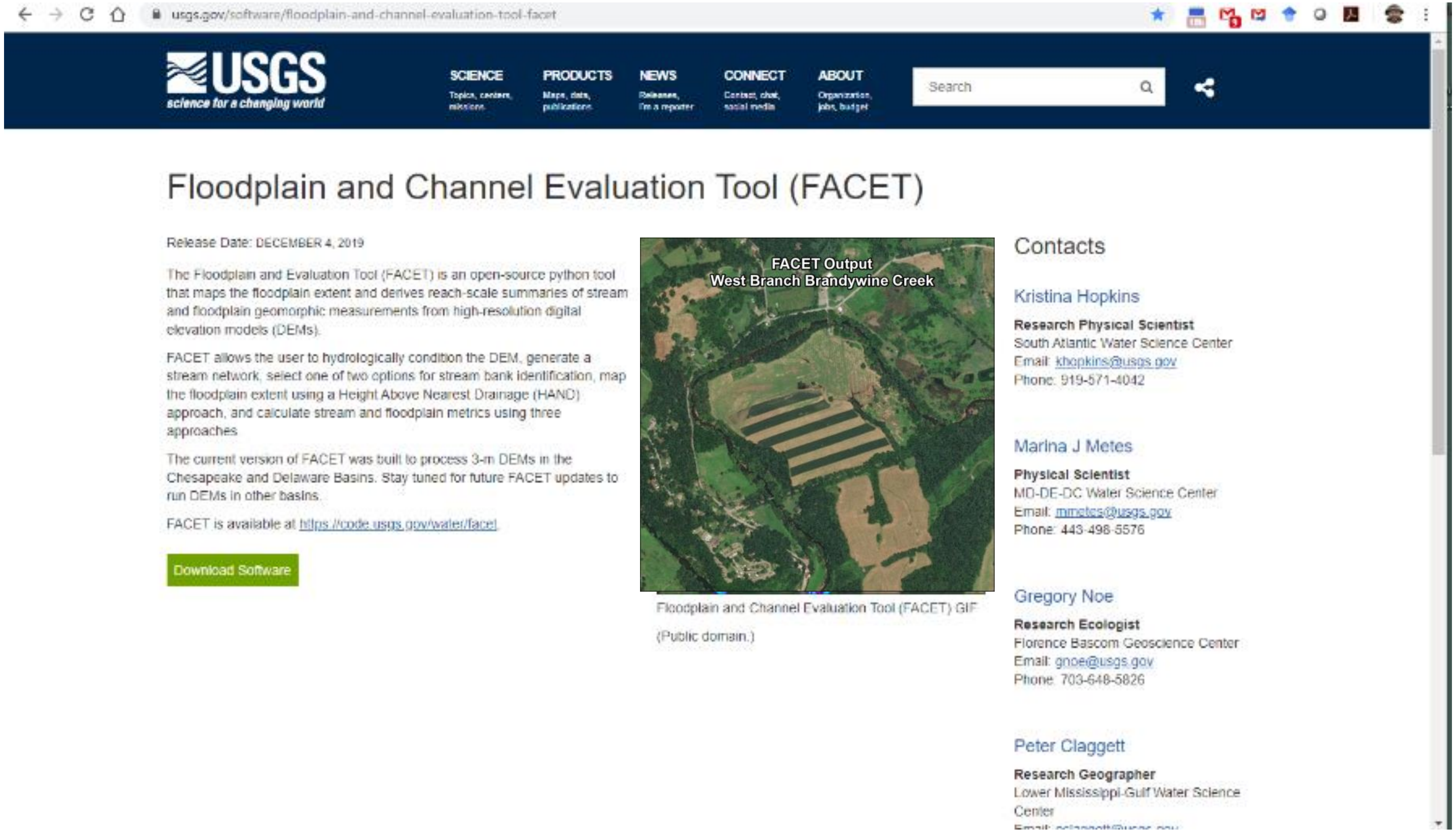


FACET workflow



Example FACET output for Wissahickon Creek at Fort Washington, PA

Floodplain and Channel Evaluation Toolkit (FACET): software

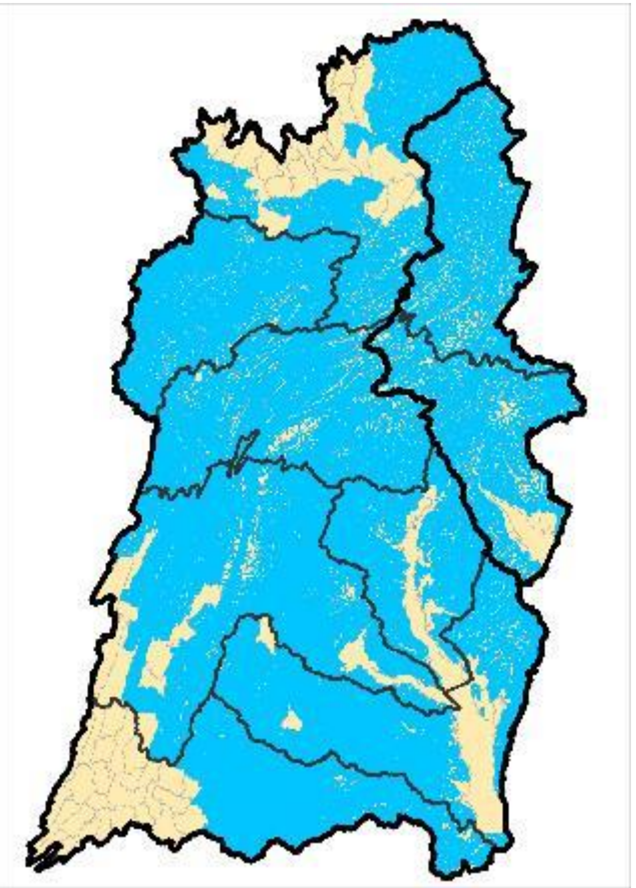


https://www.usgs.gov/software/floodplain-and-channel-evaluation-tool-facet

Lamont, S., L. Ahmed, M.J. Metes, P. Claggett, K.G. Hopkins, and G.B. Noe. 2019. Floodplain and Channel Evaluation Tool (FACET). Version 0.1.0. [Software release]. U.S. Geological Survey. DOI: https://doi.org/10.5066/P9PI94Z1.

Floodplain and Channel Evaluation Toolkit (FACET): output

Geomorphometry for Streams and Floodplains in the Chesapeake and Delaware Watersheds

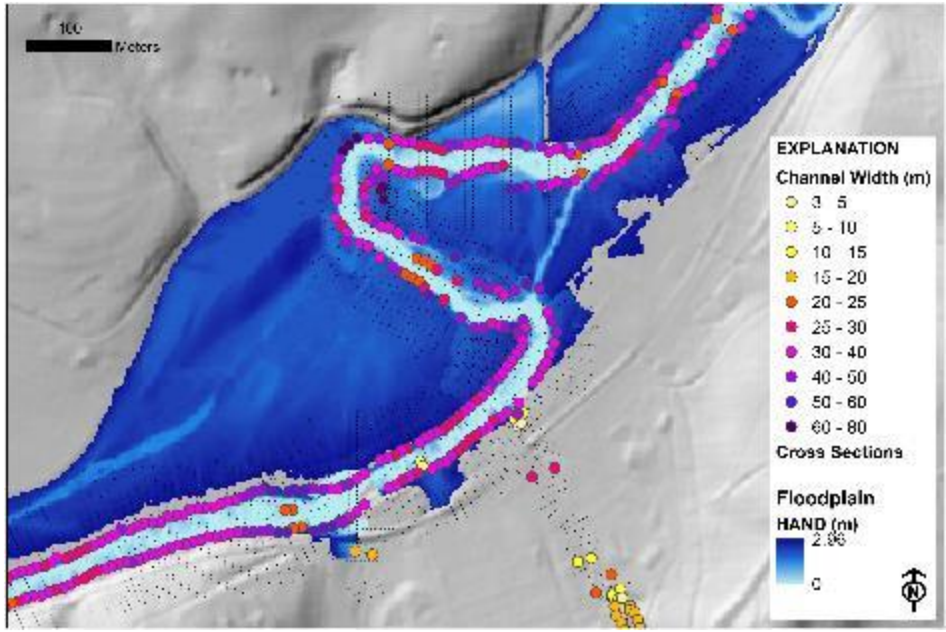


Extent of stream layer output

Every watershed with LIDAR

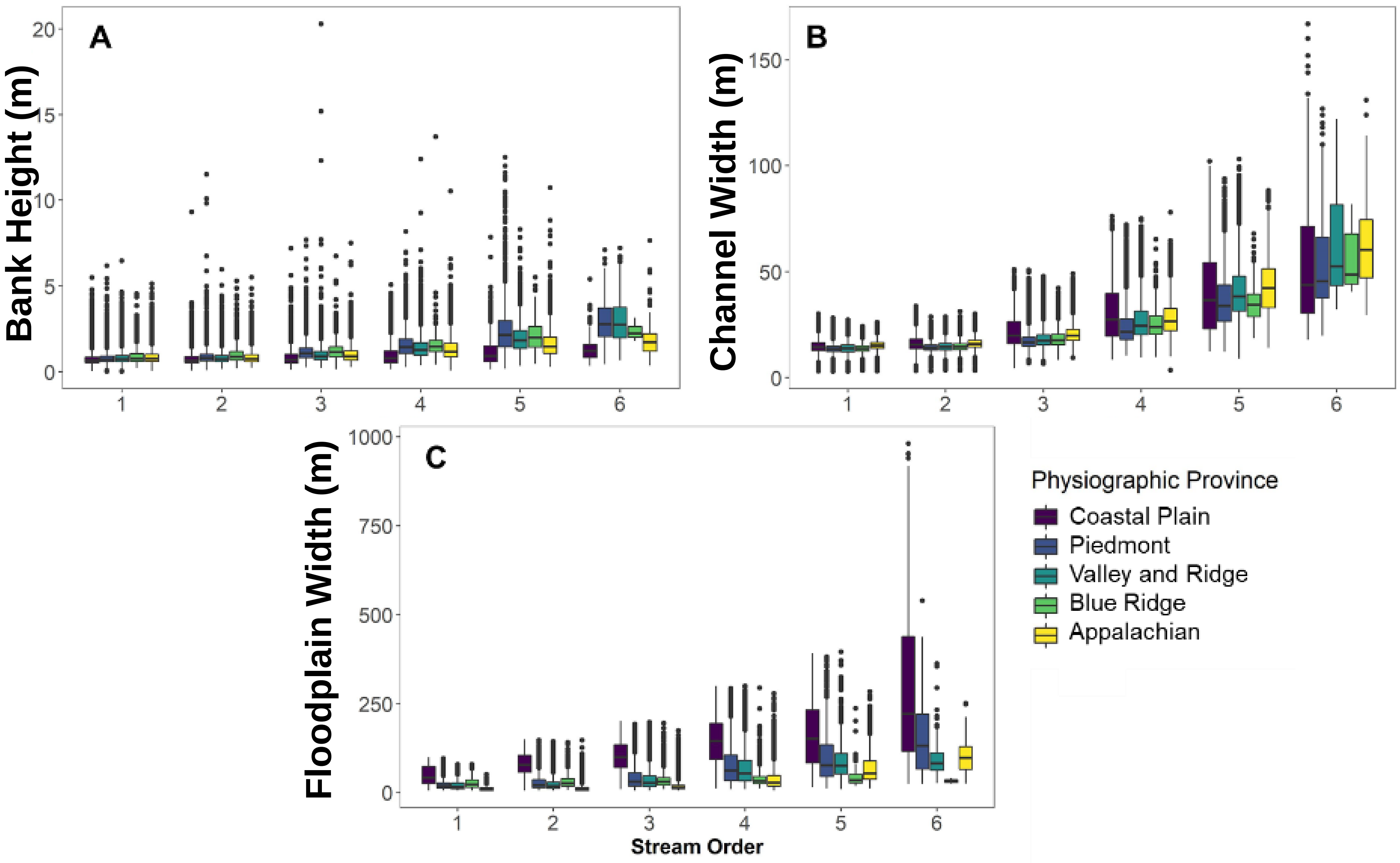
GIS: shapefiles and rasters of the stream network, cross sections, streambank point locations, floodplain extent, height above nearest drainage (HAND)

Tables: reach-scale summaries of bank height, channel width, floodplain width, and a suite of other metrics



Hopkins, K.G., Ahmed, L., Metes, M.J., Claggett, P.R., Lamont, S., and Noe, G.B, 2020, Geomorphometry for Streams and Floodplains in the Chesapeake and Delaware Watersheds: U.S. Geological Survey data release, https://doi.org/10.5066/P9RQJPT1.

1-D Cross-Section Output for ~270,000 stream reaches



Data Release: Hopkins et al. 2020, https://doi.org/10.5066/P9RQJPT1

FACET Data

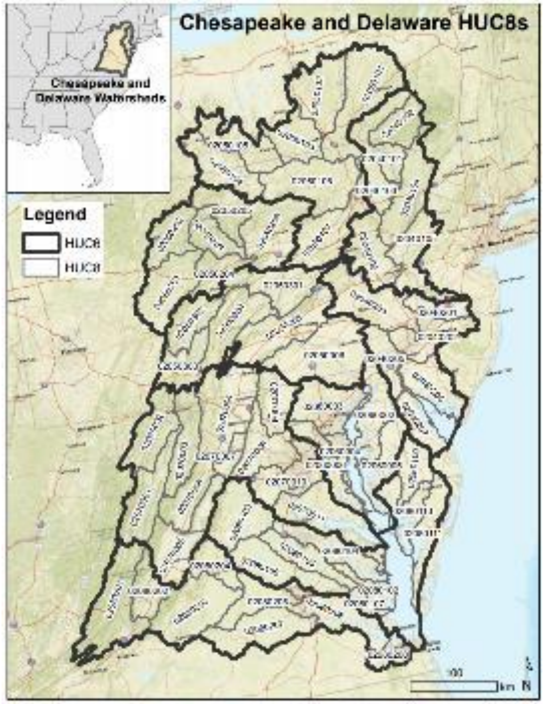
ScienceBase.gov search for
“Geomorphometry Chesapeake”

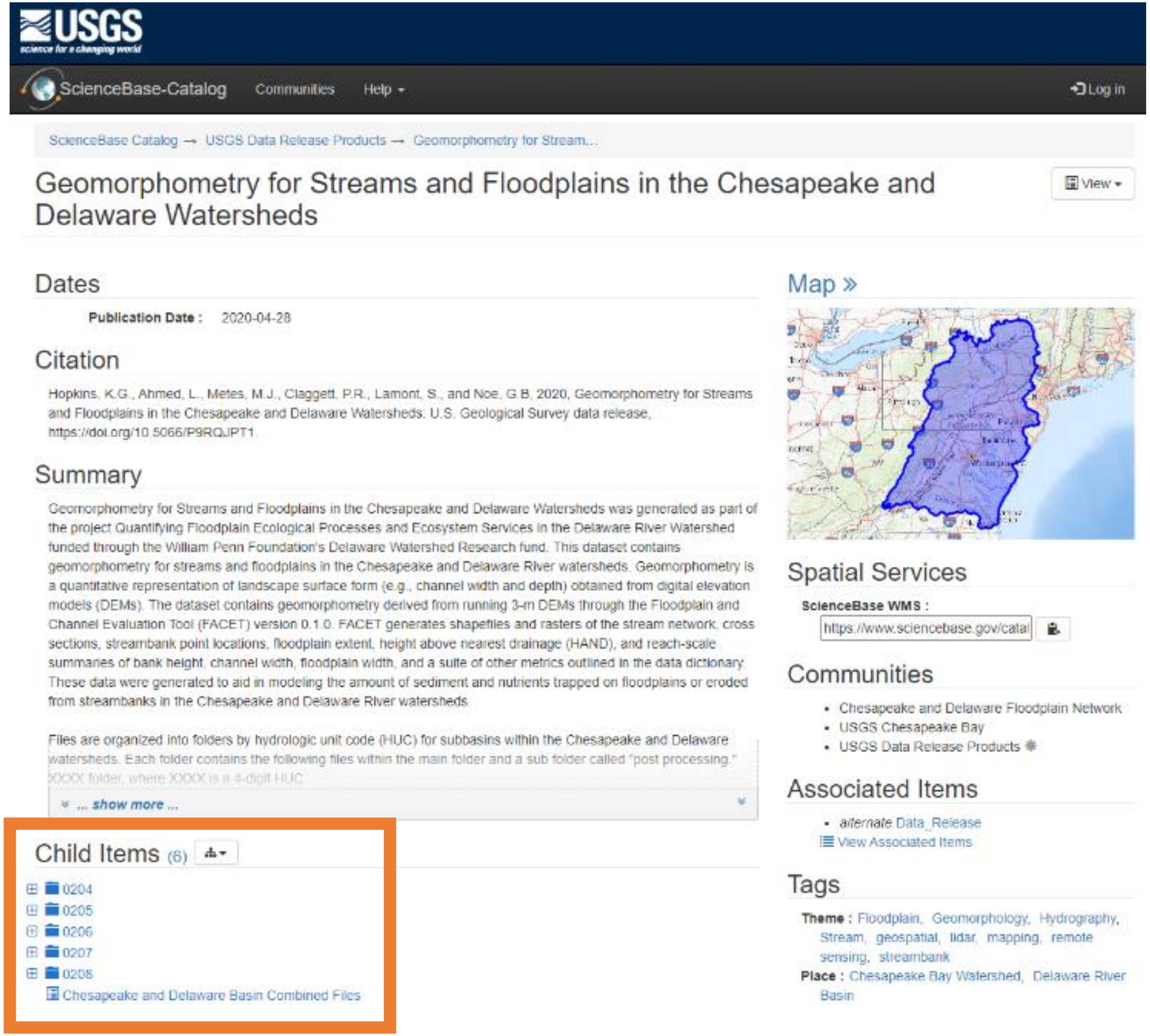
OR

https://doi.org/10.5066/P9RQJPT1

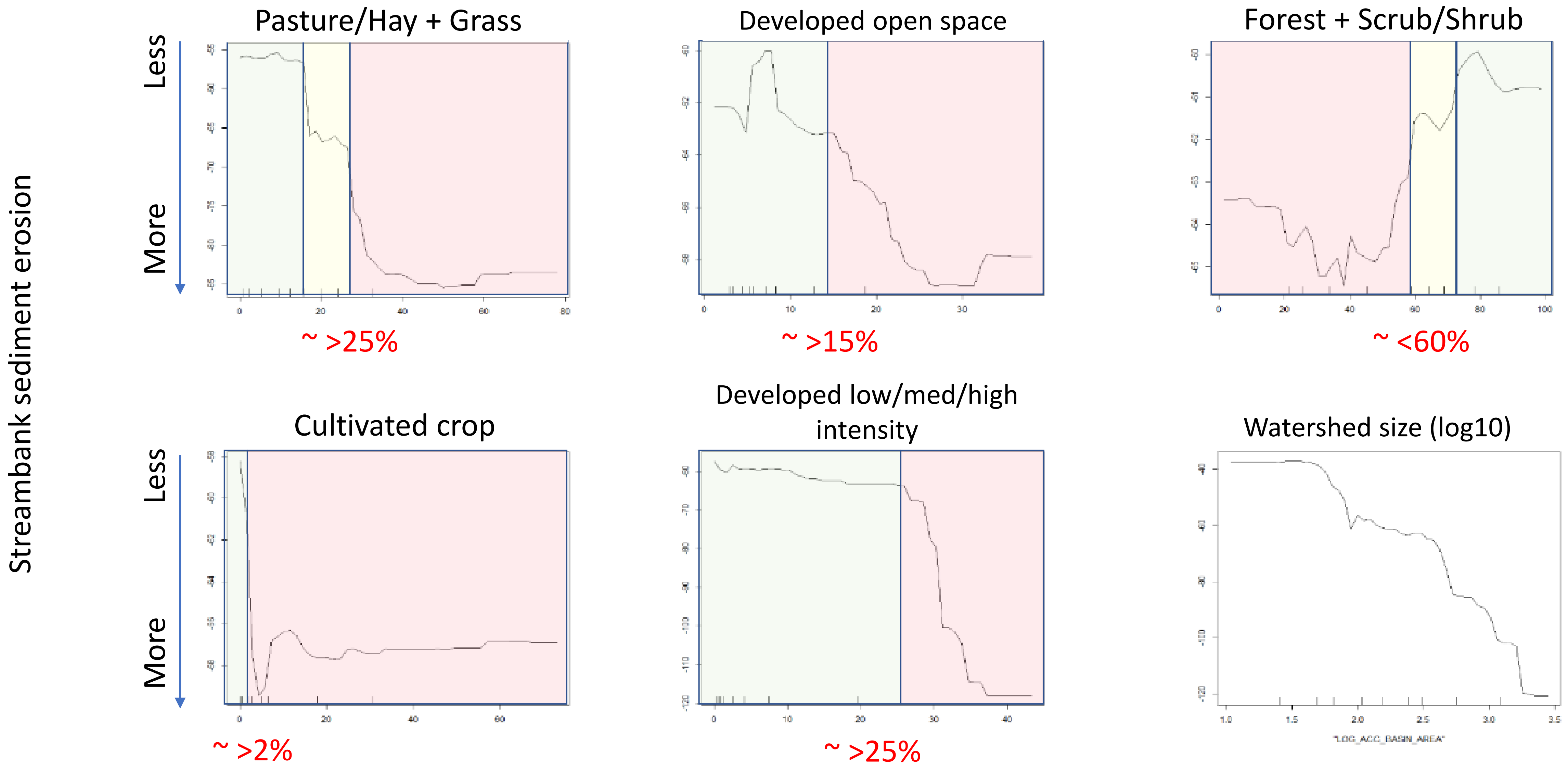
Attached Files:

Use Reference Map to find HUC#



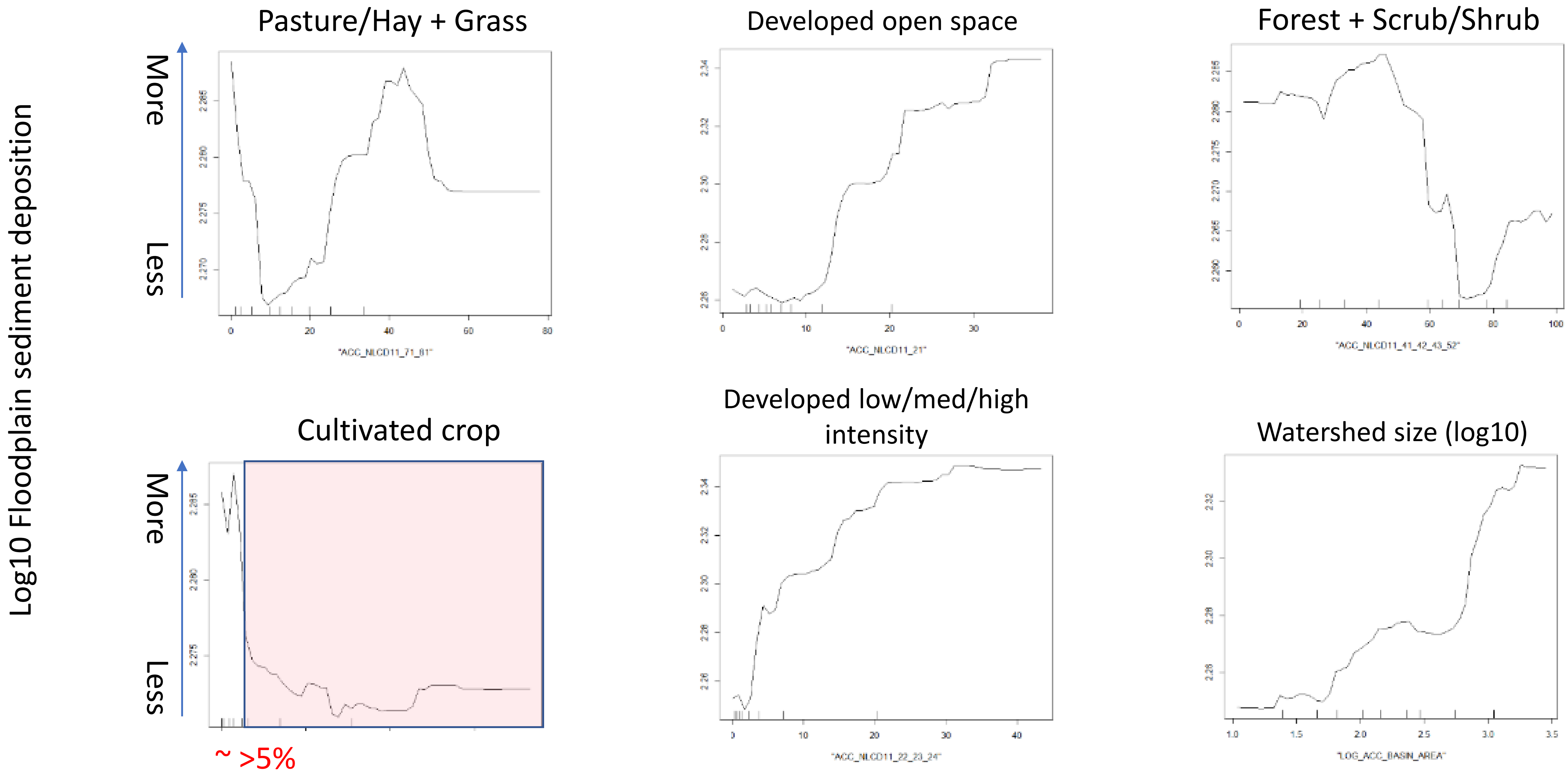


Modeled 2011 Land use effects on Streambank sediment flux (kg/m/yr)

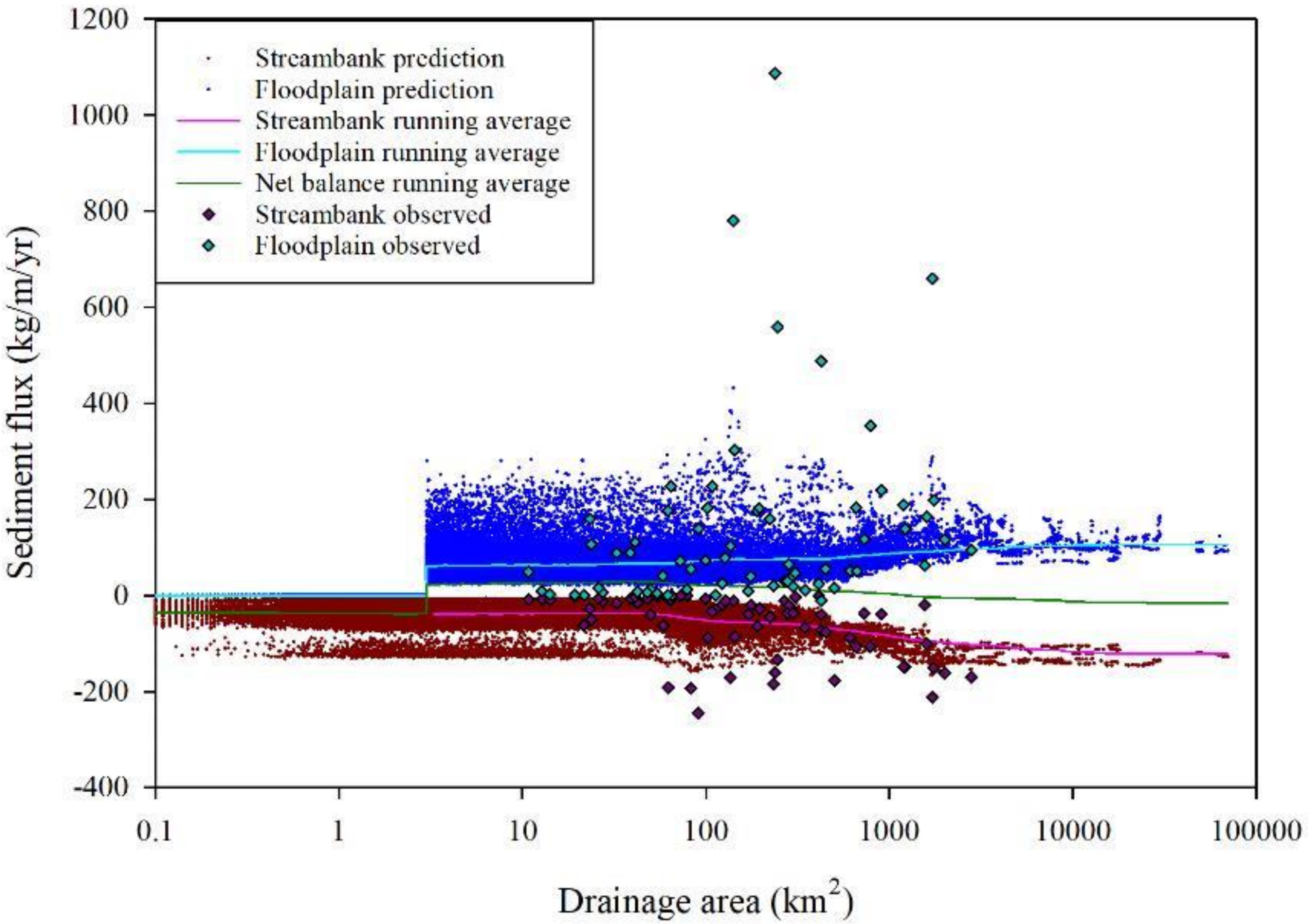


These data are preliminary and are subject to revision. They are being provided to meet the need for timely 'best science' information. The assessment is provided on the condition that neither the U.S. Geological Survey nor the United States Government may be held liable for any damages resulting from the authorized or unauthorized use of the assessment.

Modeled 2011 Land use effects on log10 Floodplain sediment flux (kg/m/yr)



Predictions for each of the 74,133 nontidal streams in the mid-Atlantic



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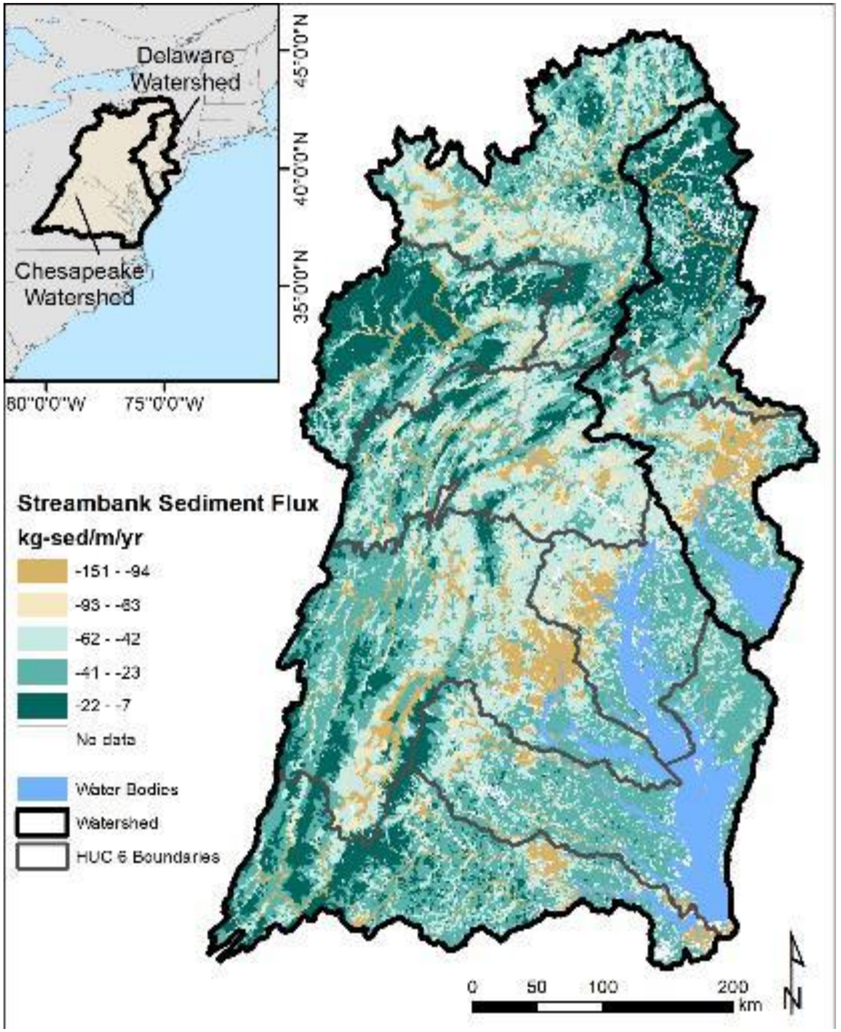
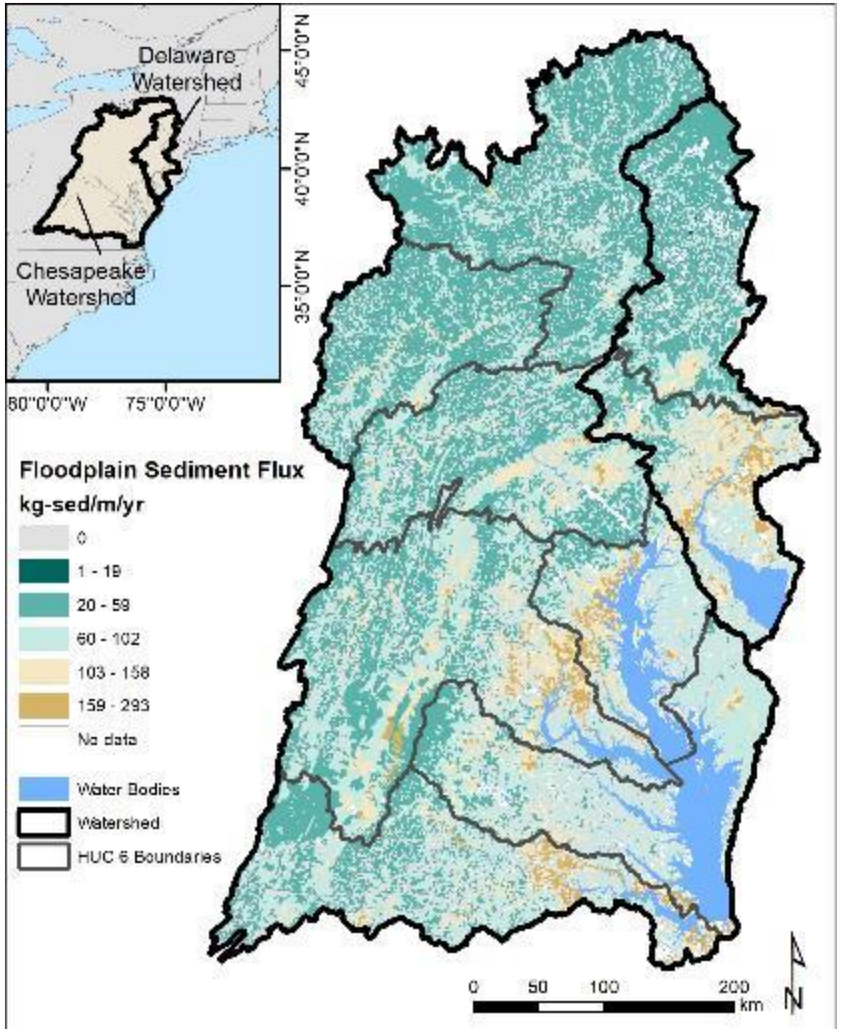
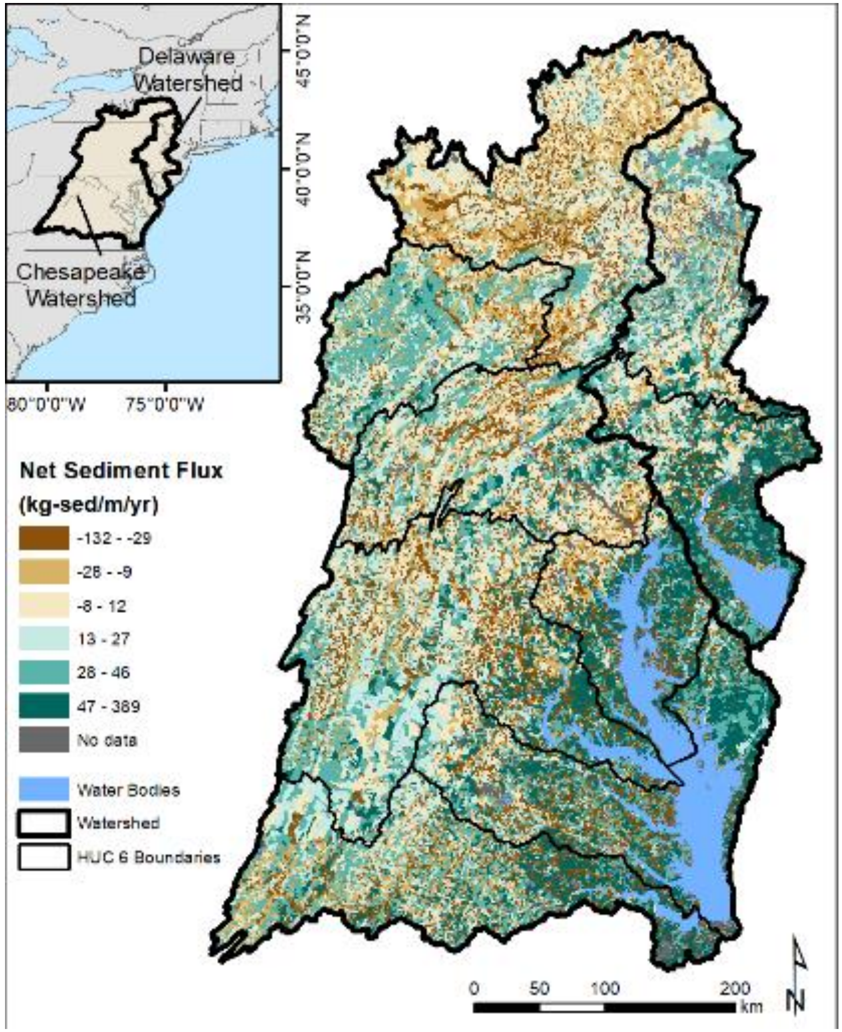
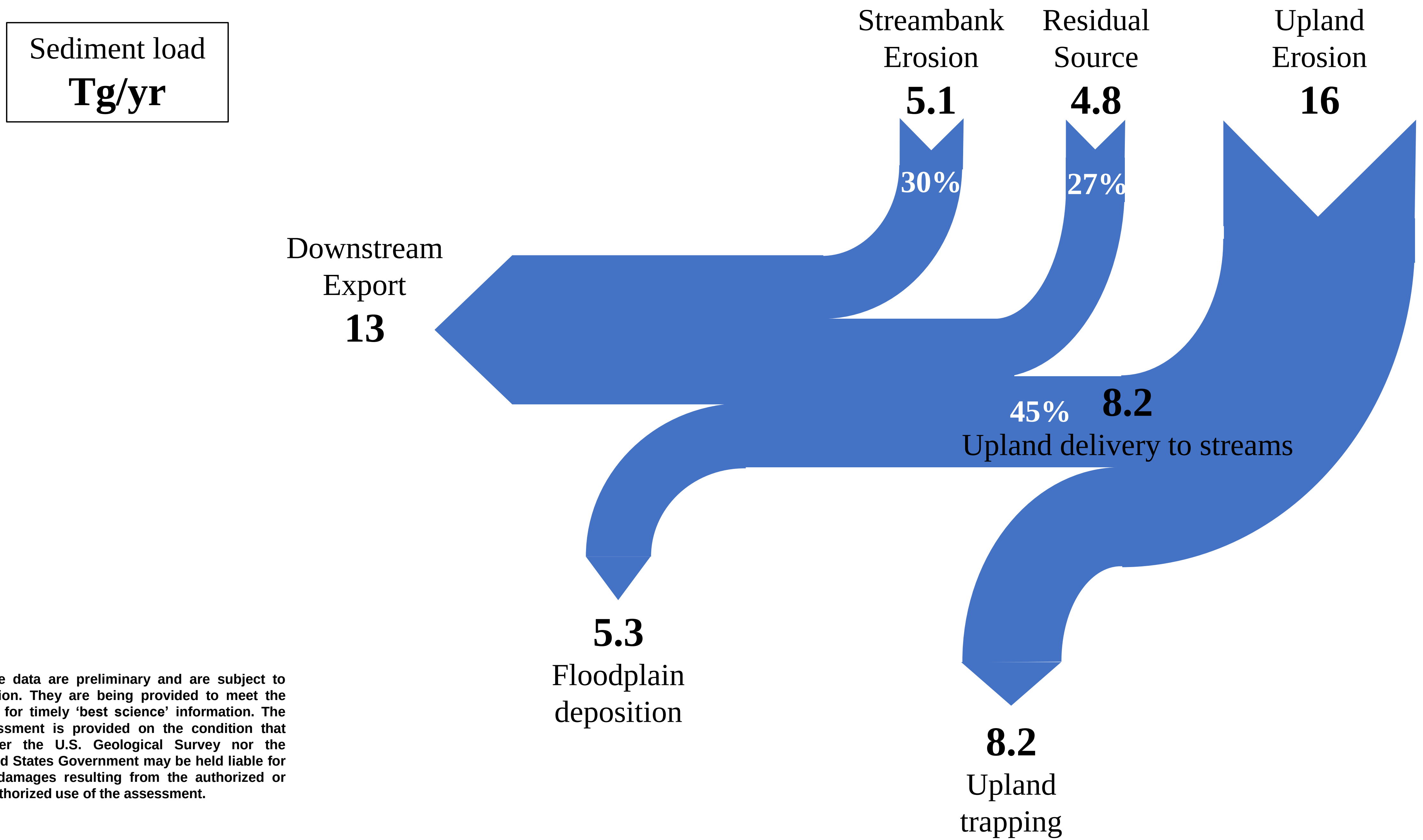
Predictions for each of the nontidal streams in the mid-Atlantic





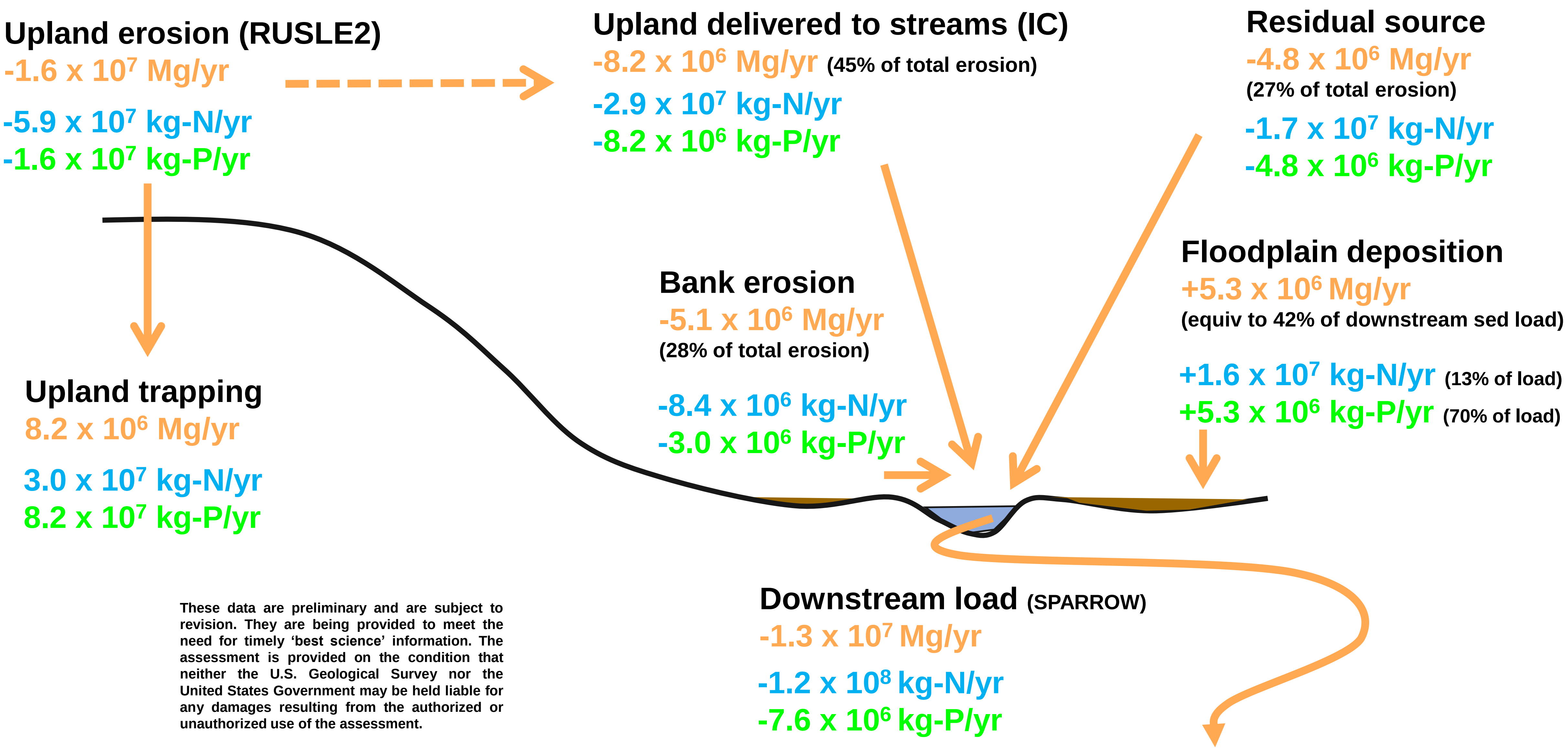


Censored loads summed for all Chesapeake watershed 64,294 nontidal NHDPlusV2 reaches

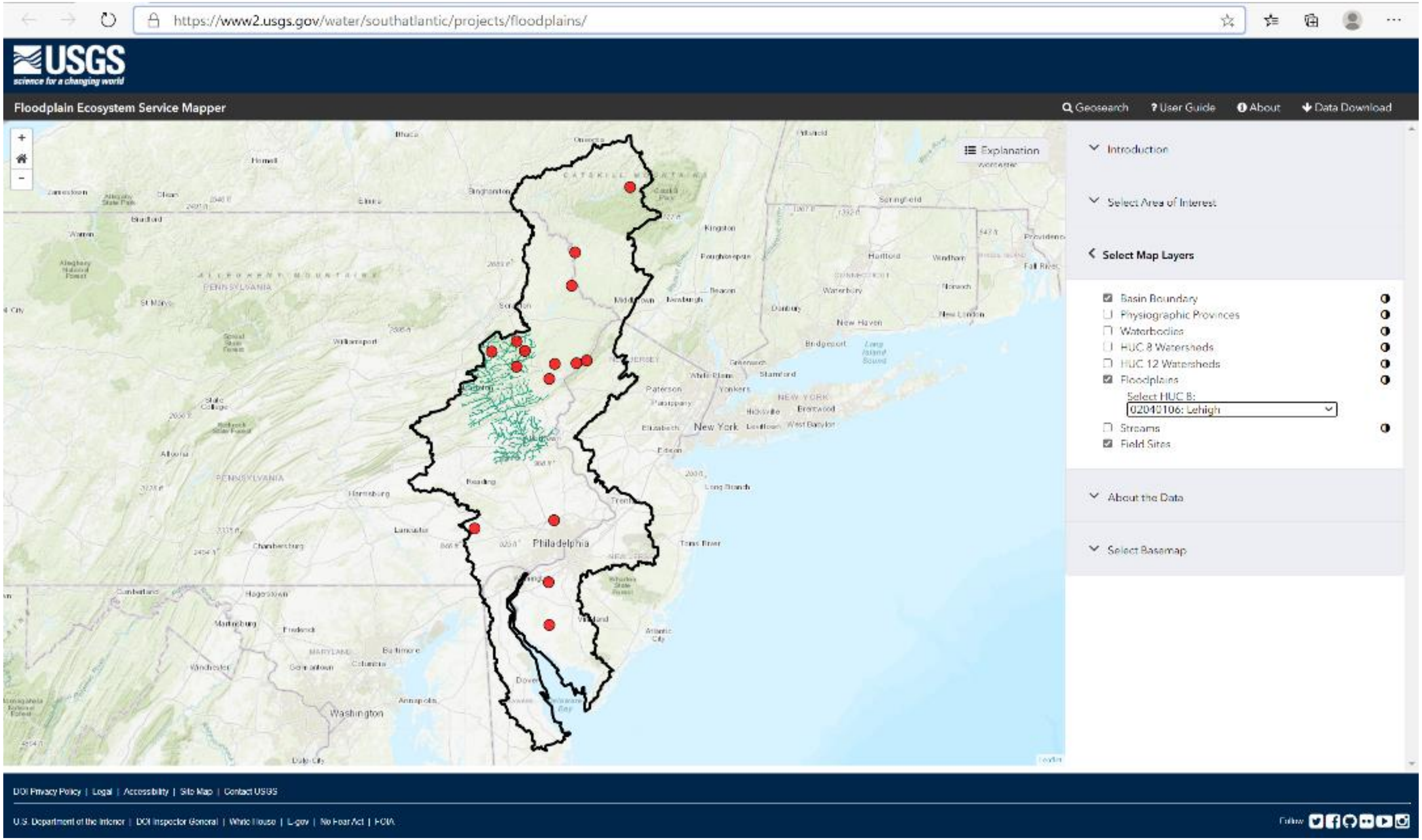


Censored loads summed for all Chesapeake watershed 64,294 nontidal NHDPlusV2 reaches

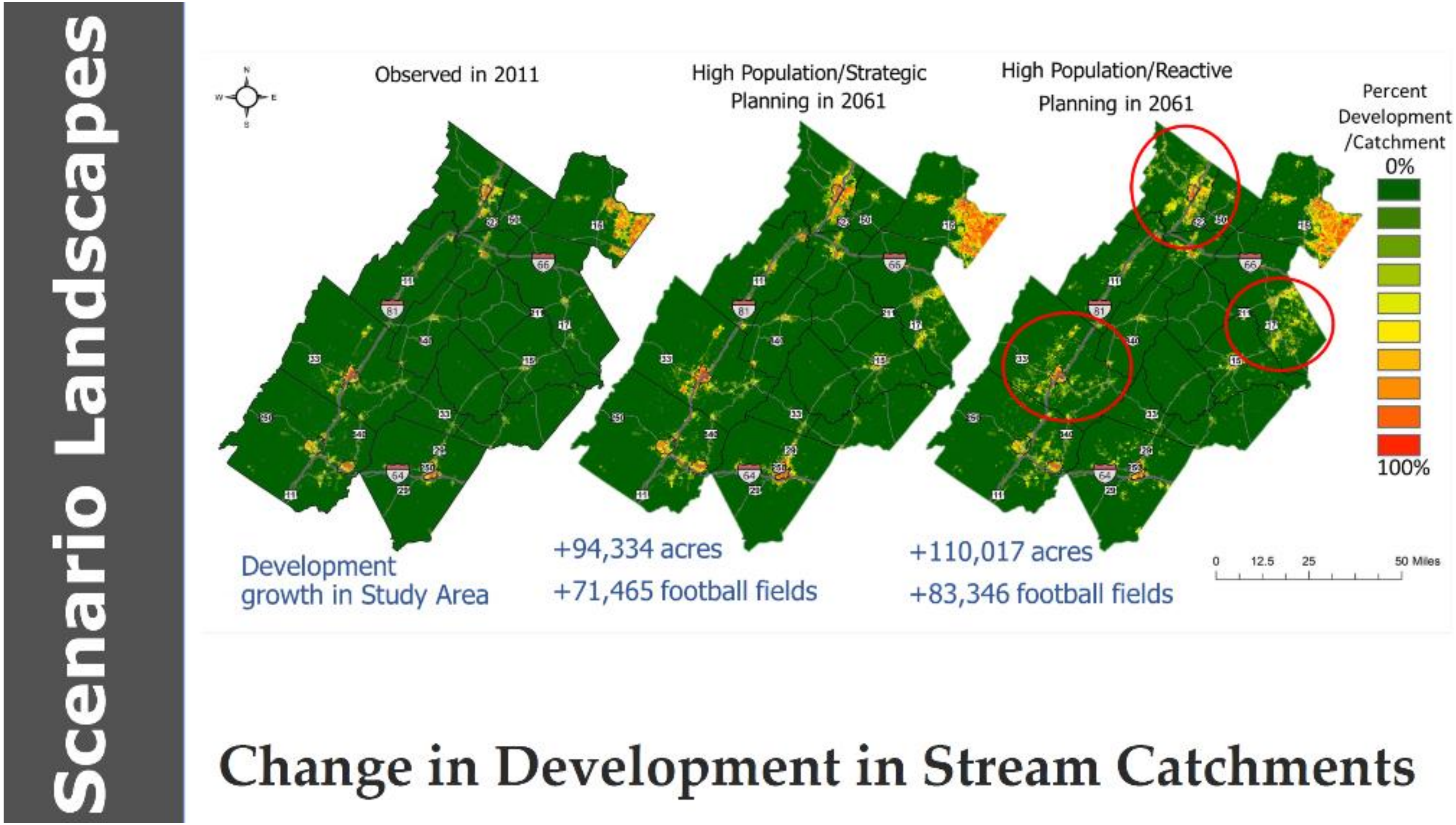
Budget: sediment, N, P



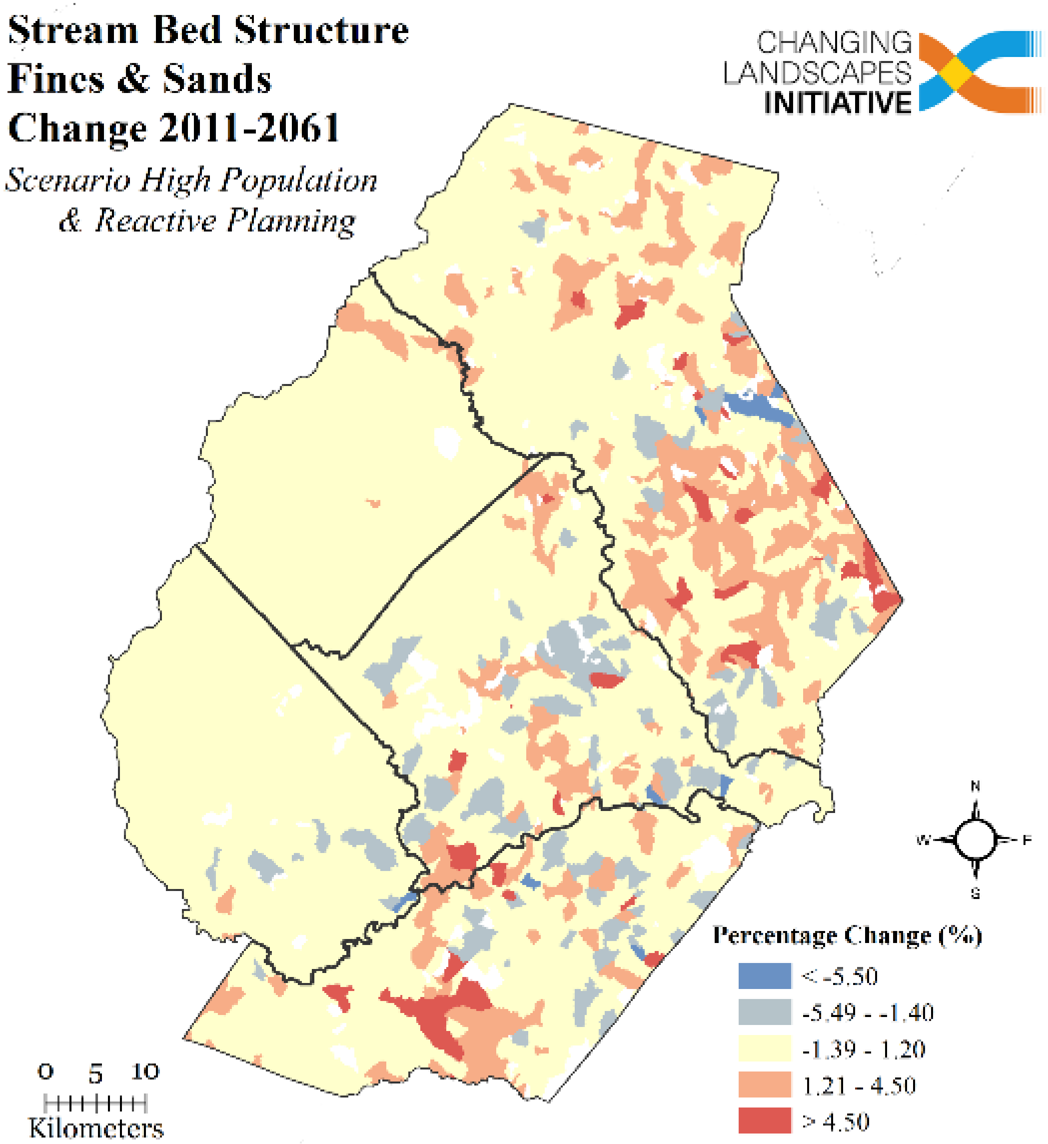
https://www2.usgs.gov/water/southatlantic/projects/floodplains/

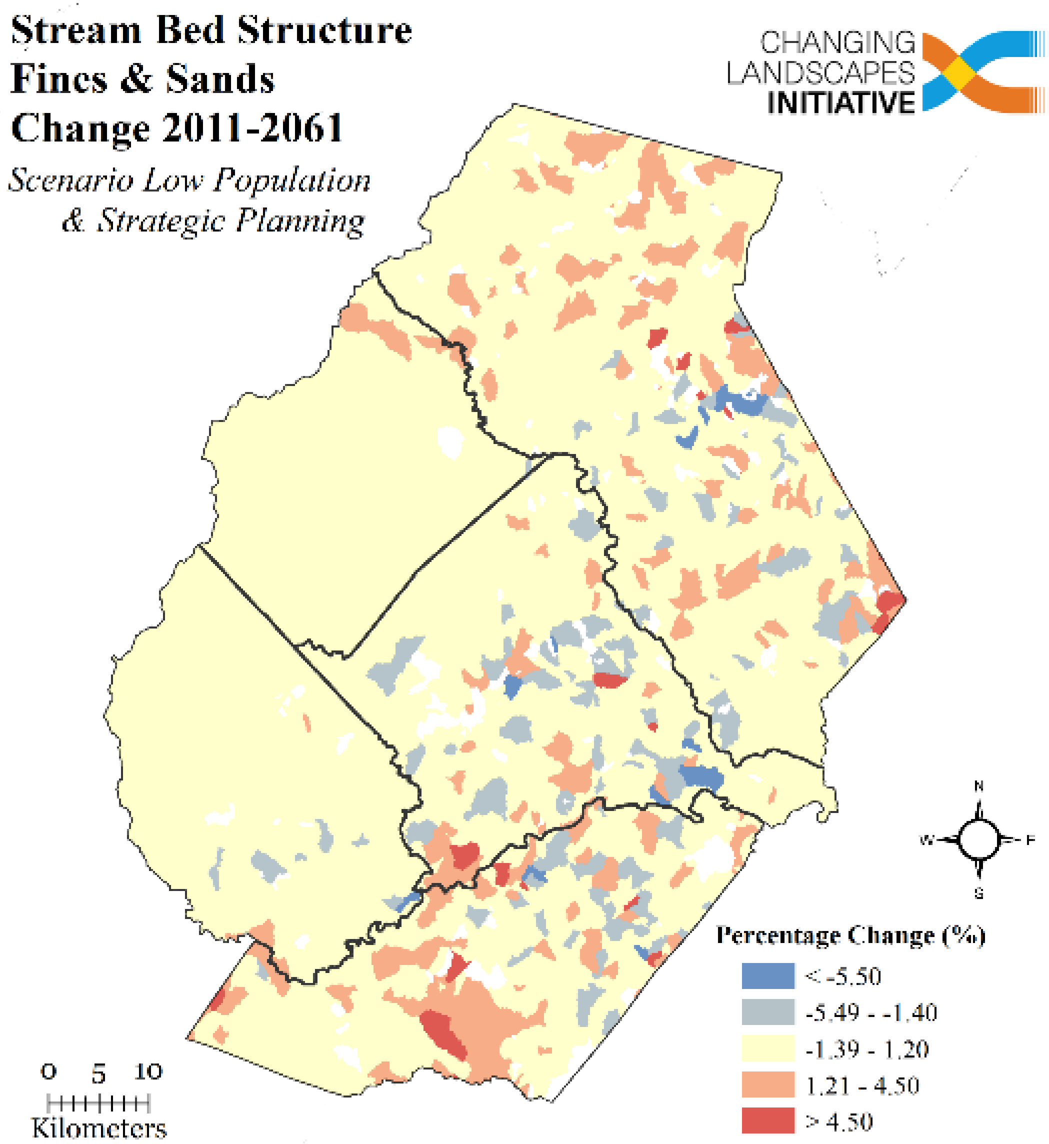


Future land use scenarios: 2061 development strategies



Future land use scenarios: 2061 change in streambed fines+sands cover





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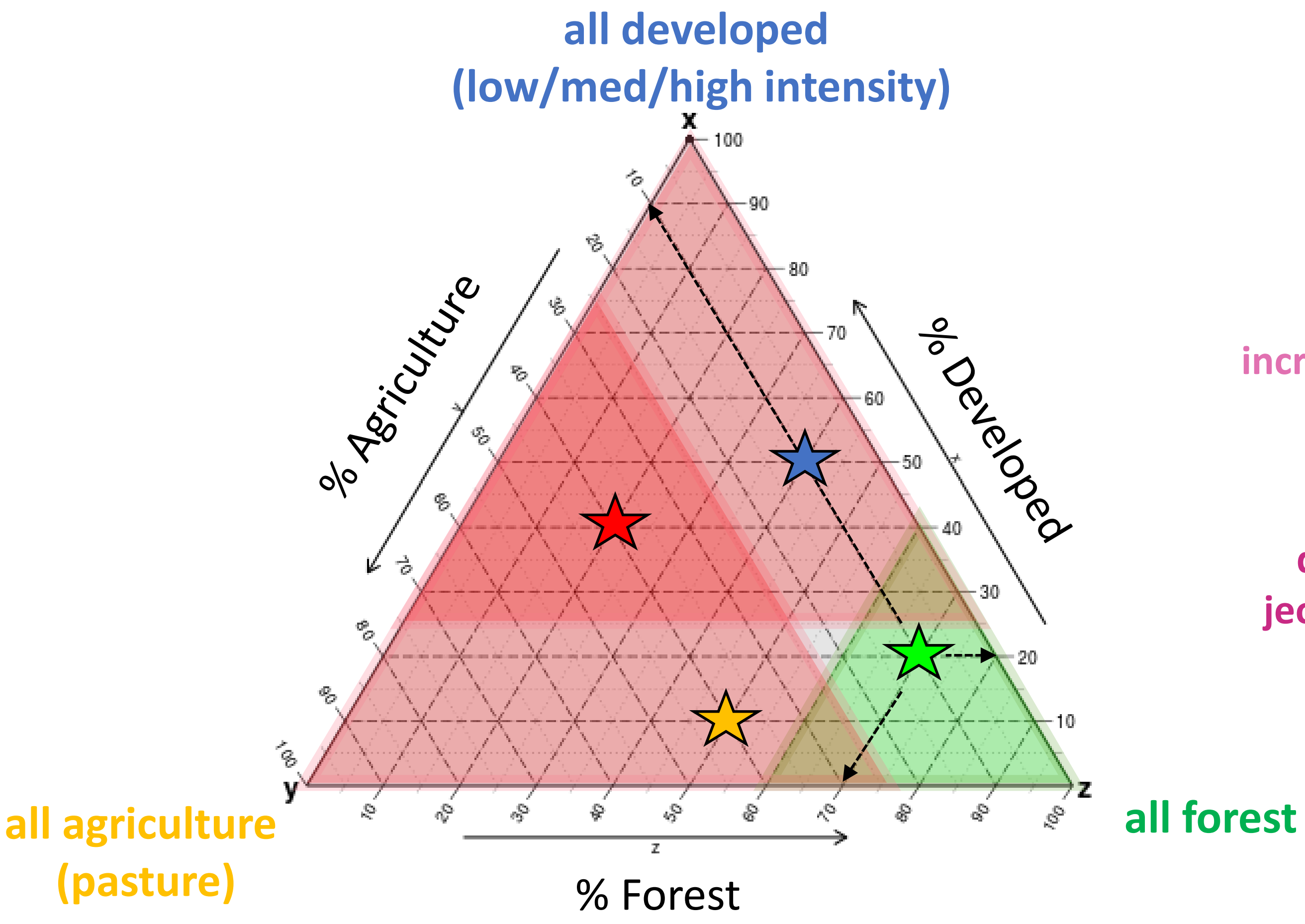
Thresholds of mixed land-use for worsening streambank sediment erosion



Examples:

low — 70% forest, 20% developed, 10% agriculture

increasing — 40% forest, 60% developed, 10% agriculture

50% forest, 10% developed, 40% agriculture

double jeopardy — 20% forest, 40% developed, 40% agriculture

Growing capabilities are enabling new approaches for measuring and modeling fluvial geomorphic change and its influence on modulating watershed transport of pollutants, from reaches to regions

- In the scale of the U.S. Mid-Atlantic, floodplain deposition and streambank erosion have been in balance for past 20-50 yr
- Floodplain and streambank fluxes are very important components of reach + regional sediment + nutrient budgets
- Reach-scale floodplain and streambank attributes and flux data can help resource managers assess and plan for management actions to reduce downstream loading

Thanks to all (38 of us) who have helped over the past 7 years!!!

Jackie Batson, Adam Benthem, Norm Bourg, Carissa Chambers, Tom Doody, Mitchell Doyle, Kelly Floro, Kacey Garber, Jaimie Gillespie, Stephanie Gordon, Jiyan Hatami, Todd Knobbe, Alicia Korol, Mateusz Kowalski, Andrew Kunz, Sam Lamont, Mario Martin-Alciati, Christina Mirda, Jane Oswalt, Shannon Pace, Grant Palmer, Eleanor Rappolee, Emma Rieb, SCBI interns, Sydney Salley, Sam Schoenmann, Patty Sullivan, Sara Ulrich, Bobby Voeks, Gabe Westergren

Random Forest models

	Bank sediment flux	Bank fine sediment flux	Bank sediment-C flux	Bank sediment-N flux	Bank sediment-P flux	Bank lateral erosion rate	Bank area eroded	Floodplain sediment flux	Floodplain fine sediment flux	Floodplain sediment-C flux	Floodplain sediment-N flux	Floodplain sediment-P flux	Floodplain area deposition	Streambed d50	Streambed %fines	Streambed %fines+sands
% Var explained	30.4	30.1	26.4	31.1	27.4	15.1	32.0	25.9	31.2	28.4	22.5	9.6	15.0	52.2	26.1	58.3
Term	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE	%IncMSE
Log drainage area (km2)	23.3	12.0	11.3	6.8	11.2	NIM	17.9	10.8	5.3	5.2	5.4	1.8	4.0	NIM	NIM	NIM
Erodibility factor	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	0.3	NIM	NIM	NIM
Soil < 74 µm (%)	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	4.2	NIM	NIM	-0.1	1.8	NIM	NIM	NIM
Base flow index (%)	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	3.1	NIM	NIM	2.4	2.9	NIM	NIM	NIM
Topographic wetness index	NIM	NIM	NIM	NIM	4.5	NIM	5.2	8.0	6.5	NIM	3.1	4.1	2.5	13.5	15.9	17.8
1951-2000 average annual runoff (mm)	6.6	7.2	9.7	5.2	5.6	NIM	6.6	7.9	7.4	6.0	5.5	2.4	2.6	NIM	4.6	NIM
Horton overland flow (%)	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	2.9	NIM	3.6	1.3	1.6	NIM	NIM	NIM
Rock sulfur content (%)	NIM	6.6	NIM	NIM	1.9	NIM	NIM	NIM	NIM	NIM	NIM	NIM	0.4	NIM	NIM	NIM
Rock iron content (%)	NIM	NIM	5.5	NIM	3.2	NIM	NIM	5.3	2.7	5.0	3.8	1.4	2.3	10.4	3.5	15.6
Number of dams	NIM	NIM	NIM	NIM	NIM	NIM	NIM	5.3	4.9	3.8	4.4	2.5	2.5	4.0	NIM	NIM
2011 NLCD developed open space (%)	1.8	4.0	4.1	7.2	2.0	2.2	1.6	8.3	5.0	6.2	4.2	6.2	3.5	0.4	2.1	2.6
2011 NLCD developed low+med+high intensi	10.5	9.3	7.9	6.7	5.6	10.6	7.6	12.2	7.9	4.4	5.0	5.2	5.9	3.1	1.9	0.1
2011 NLCD barren land (%)	4.6	1.0	4.2	4.0	0.7	3.8	3.5	3.5	0.7	2.3	3.3	2.7	3.2	3.1	3.6	5.7
2011 NLCD forest + shrub/scrub (%)	2.0	3.7	3.5	1.8	2.4	3.2	0.3	5.4	4.6	3.3	2.6	3.1	2.6	5.0	0.7	7.5
2011 NLCD grassland + pasture/hay (%)	7.5	8.2	7.1	8.5	3.0	7.3	8.2	3.3	1.9	-0.2	-0.1	-0.1	1.2	4.6	-0.7	7.3
2011 NLCD cultivated crops (%)	6.0	4.1	5.8	5.4	3.6	3.2	4.8	6.7	4.1	3.7	4.7	3.5	4.0	7.6	3.0	10.1
2011 NLCD woody + herbaceous wetland (%)	5.1	7.1	7.1	6.6	5.2	7.3	6.8	4.4	2.9	1.1	4.1	3.4	3.0	5.3	1.0	11.4
Stream slope ()	NIM	NIM	NIM	4.9	NIM	10.3	NIM	NIM	6.4	4.4	3.7	1.8	1.8	NIM	NIM	NIM
Stream sinuousity	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	1.2	NIM	0.8	NIM	NIM	NIM
Streambank height (m) 7525mean_1D	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	0.0	NIM	NIM	NIM
Channel width (m) 7525mean_1D	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	0.3	NIM	NIM	NIM
Floodplain width (m) mean_1D	NIM	NIM	10.3	6.0	NIM	6.8	NIM	10.3	6.0	6.2	6.4	5.8	5.9	NIM	NIM	NIM
Bank angle mean (degrees) 7525mean_1D	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	2.7	3.0	2.4	NIM	NIM	NIM
Channel width / Streambank height	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	2.0	0.8	1.0	1.1	NIM	NIM	NIM
Channel width / Floodplain width	NIM	NIM	NIM	NIM	NIM	NIM	NIM	6.5	4.8	4.6	5.5	4.0	3.6	NIM	NIM	NIM
Floodplain width / Streambank height	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	5.0	4.8	3.9	1.7	9.3	NIM	NIM