Measuring and predicting the input and loss of sediment and nutrients from floodplains and streambanks across the Chesapeake watershed

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Understanding and scaling transport processes thru watersheds

Alluvial sediment exchange

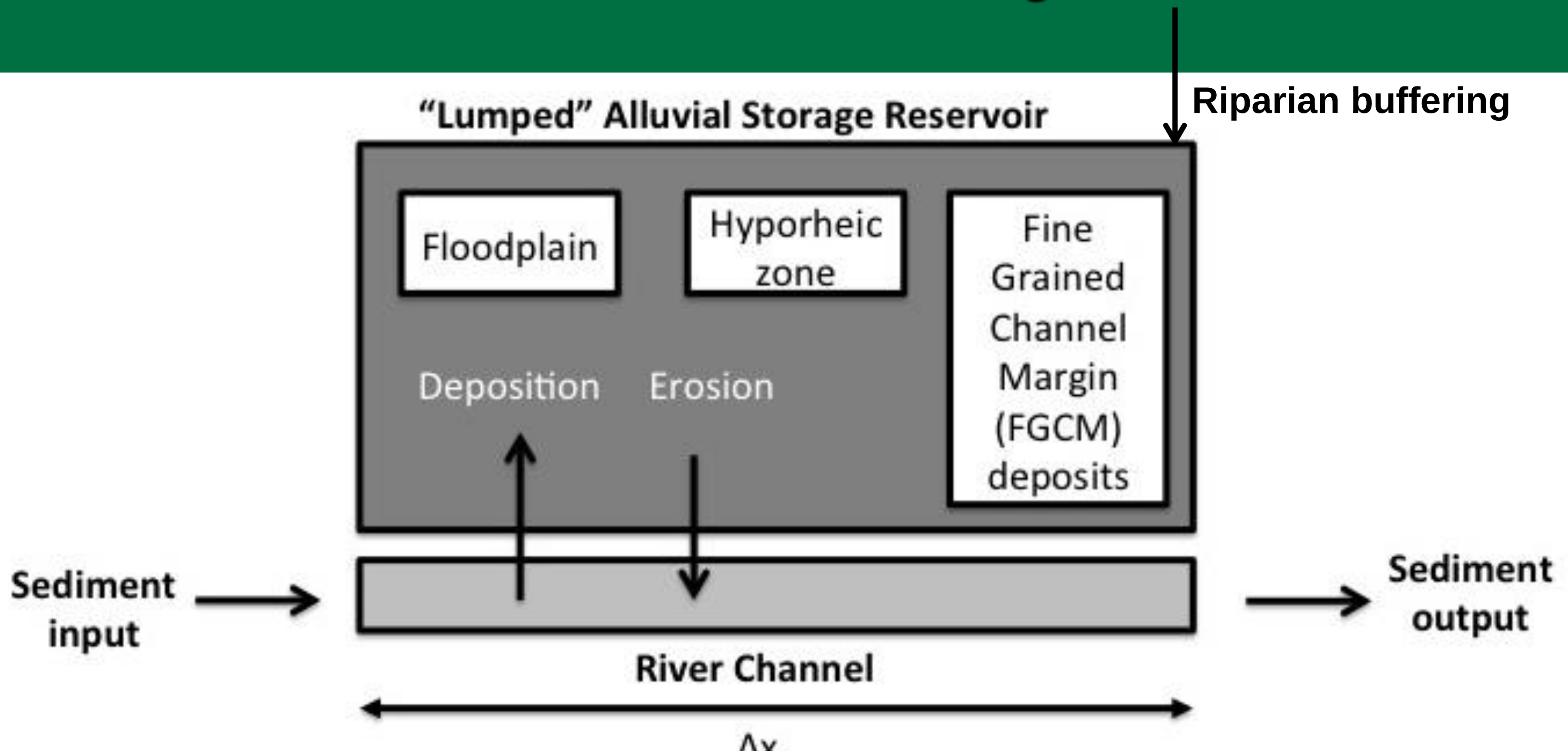

Figure 1. Spatial structure (in plan view) of a 1-dimensional "valley-averaged" suspended sediment routing model.

Modified from Benthem and Skalak

79% of P load and 28% of N load to Chesapeake Bay is particulate (Noe and Hupp 2009, from Langland et al. 2006)

The importance of floodplains to WQ in the Chesapeake watershed

Measurement of functions

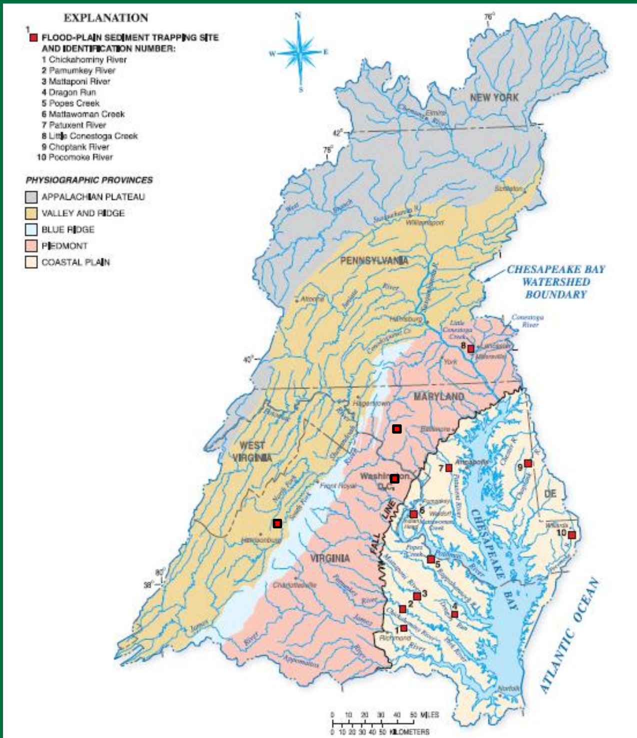

Figure 2. Location of flood-plain sediment trapping sites in the Chesapeake Bay Watershed. [Dates of measurements range from 1996 through 2006 (modified from Bachman and others, 1998).]

Ross et al. 2004
Noe and Hupp 2005
Noe and Hupp 2007
Gellis et al. 2008
Hogan and Walbridge 2009
Noe and Hupp 2009
Schenk and Hupp 2009
Kroes and Hupp 2010
Hupp et al. 2013
Schenk et al. 2013
Noe et al. 2013a
Noe et al. 2013b
Gellis et al. 2015

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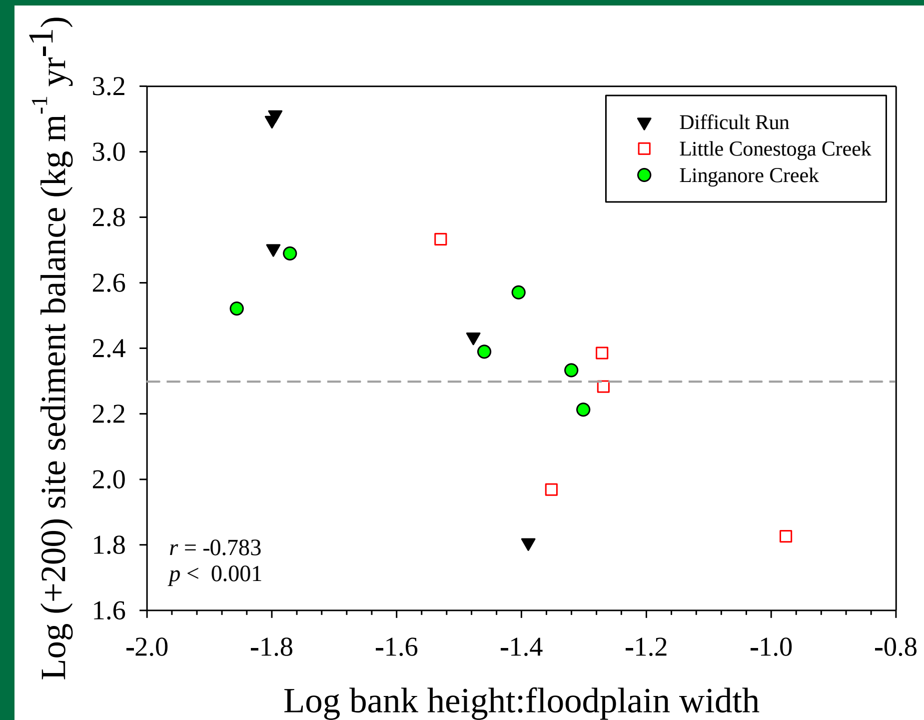
Predictability of functions



Schenk et al. 2013, *ESP&L*

Gellis et al. 2015, SIR

Only 3 Piedmont watersheds!

→ Not expected to be general, but shows promise of approach:

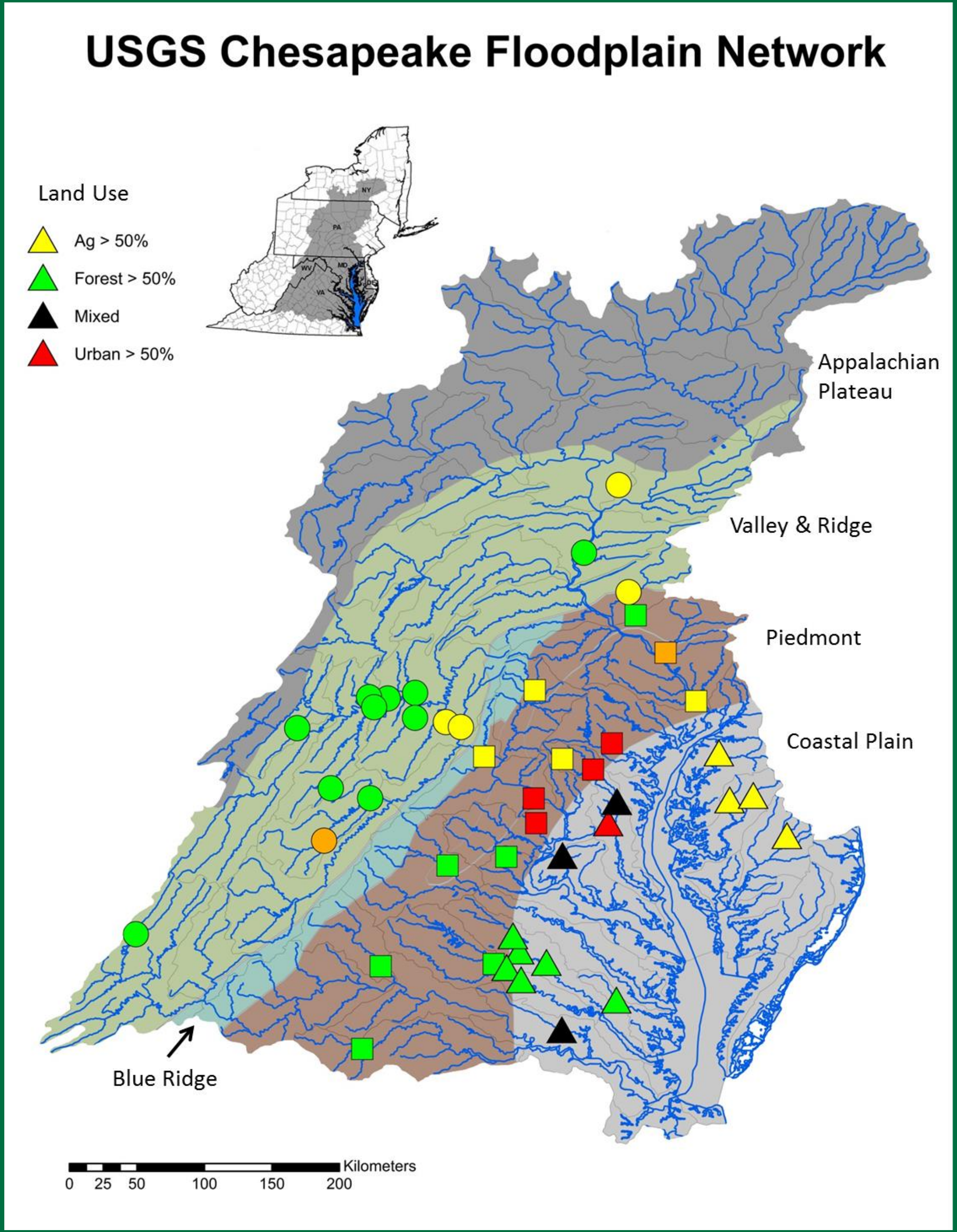
Easy geomorphic metrics may be predictive

The next leap: The USGS Chesapeake Floodplain Network

Goal:
Measure and predict the sediment/N/P balance
(sink or source of floodplain + banks)
for entire Chesapeake watershed

Site selection:

- Chesapeake NTN load gages
- 'unmanaged' floodplain land use (forest/scrub/herbaceous; not ag/ pasture/developed)
- Landowner permission
- Range of watershed size and land-use



USGS Chesapeake Floodplain Network

Measurements:

Contemporary (pin) floodplain flux
Contemporary (pin) bank flux
Long-term (dendro) floodplain flux
Long-term (dendro) bank flux

X-section survey (channel, banks, floodplain)
Longitudinal survey (tie to gage, reach slope)

Channel bed particle size

Soil/sediment TN, TP, TOC, LOI, particle size
Soil/sediment biogeochemical processes (*potential list*):

NP mineralization, denitrification potential, P sorption, microbial respiration, Veg NP limitation

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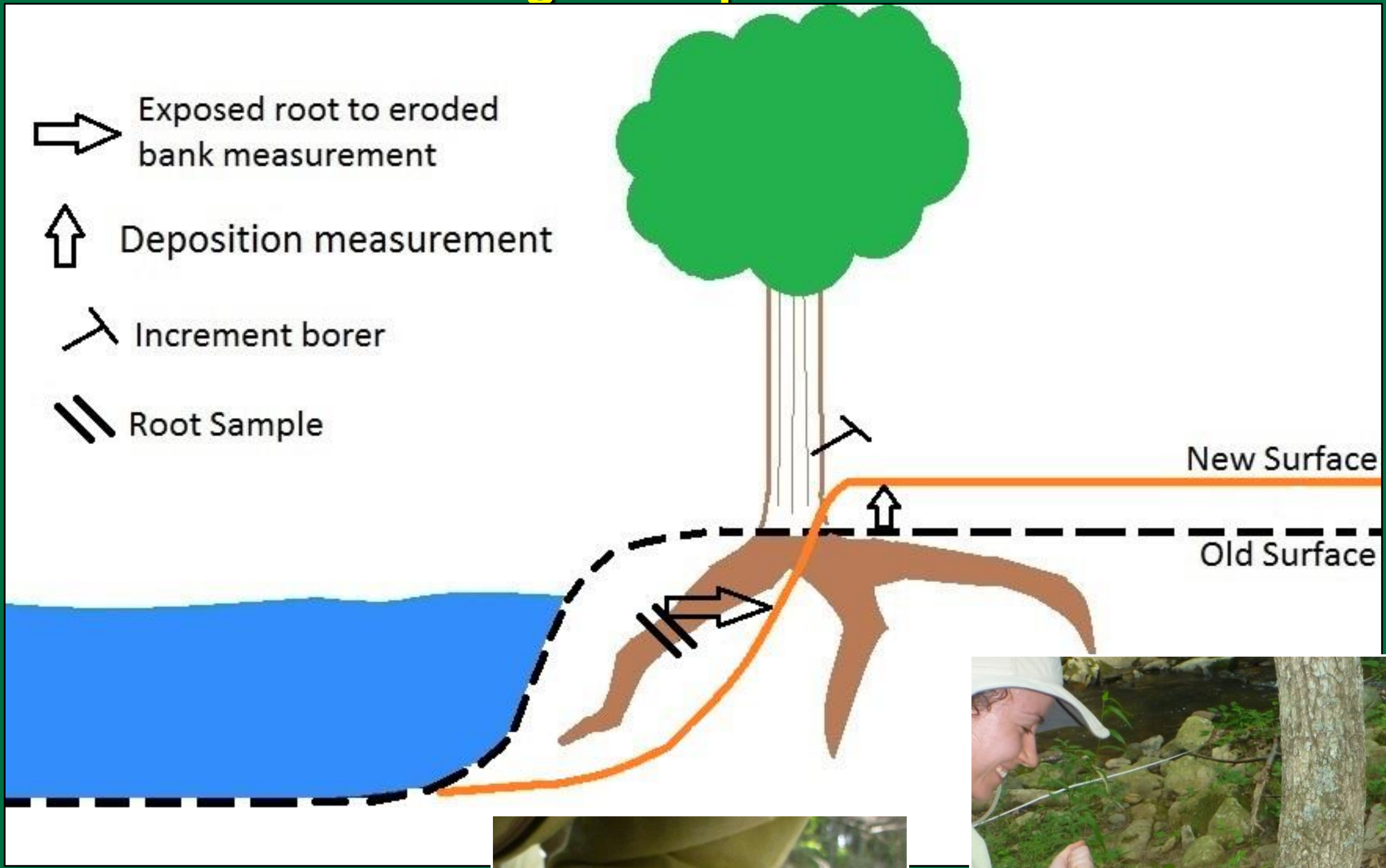
Dendrogeomorphic method



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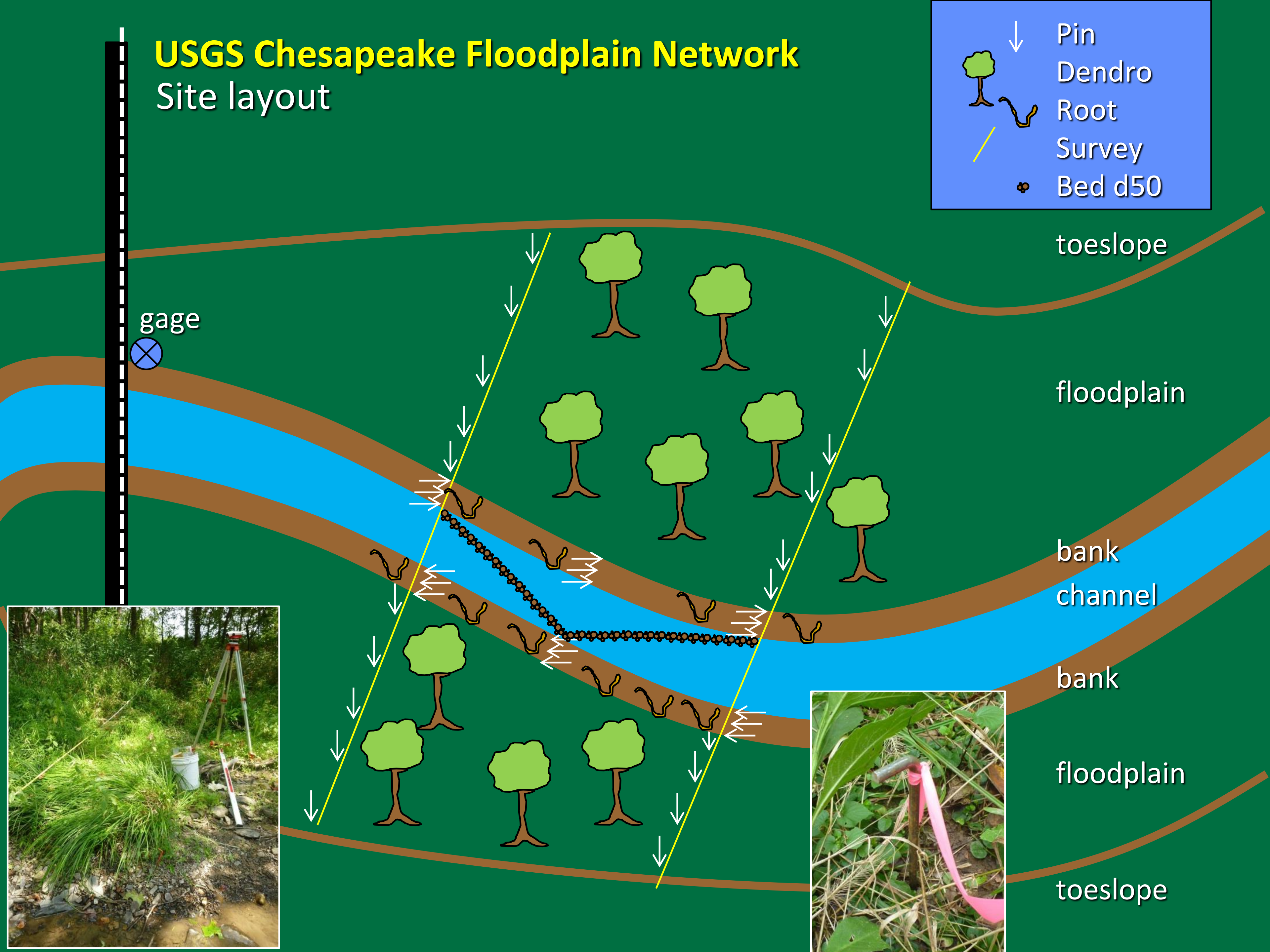
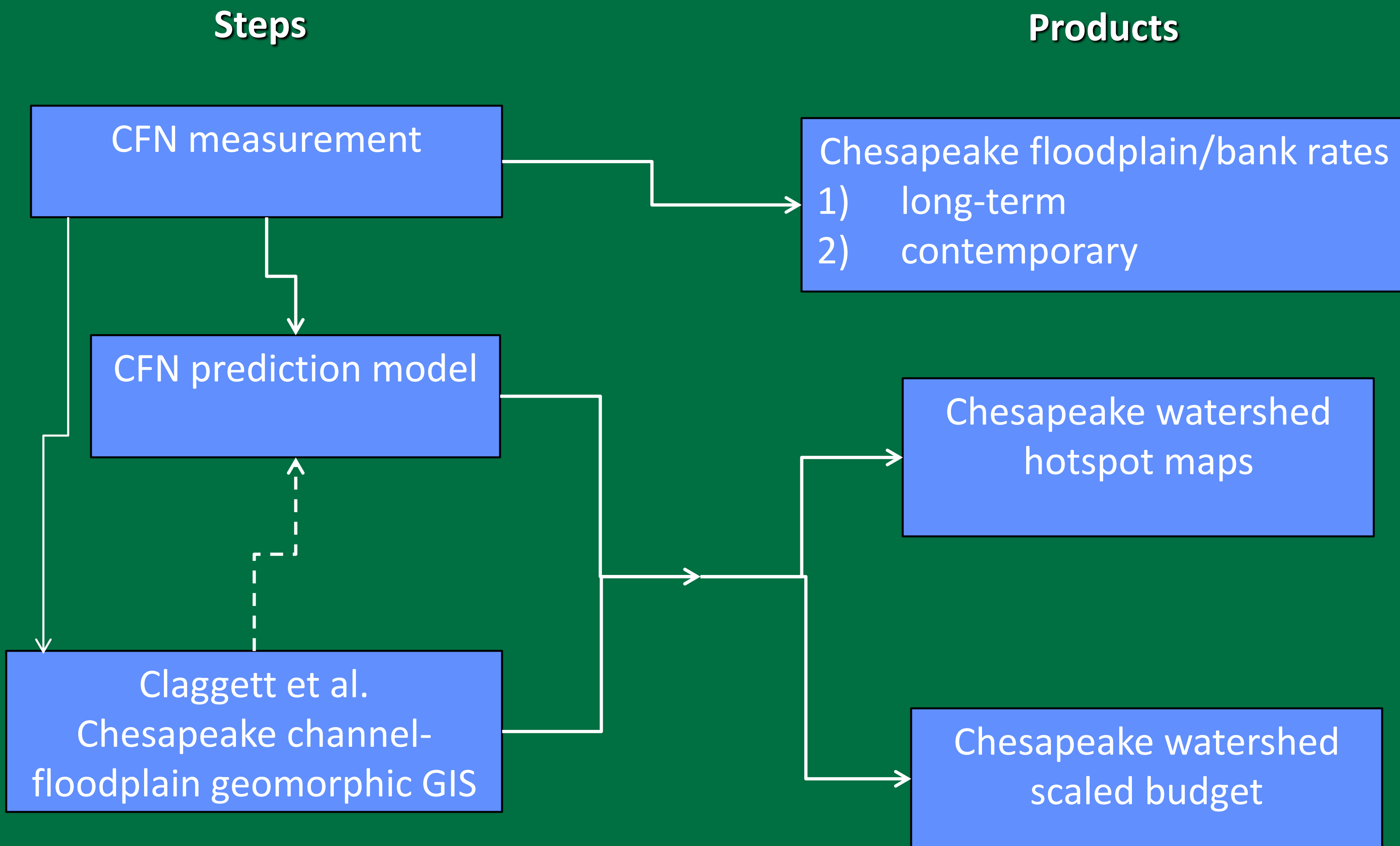
Site layout

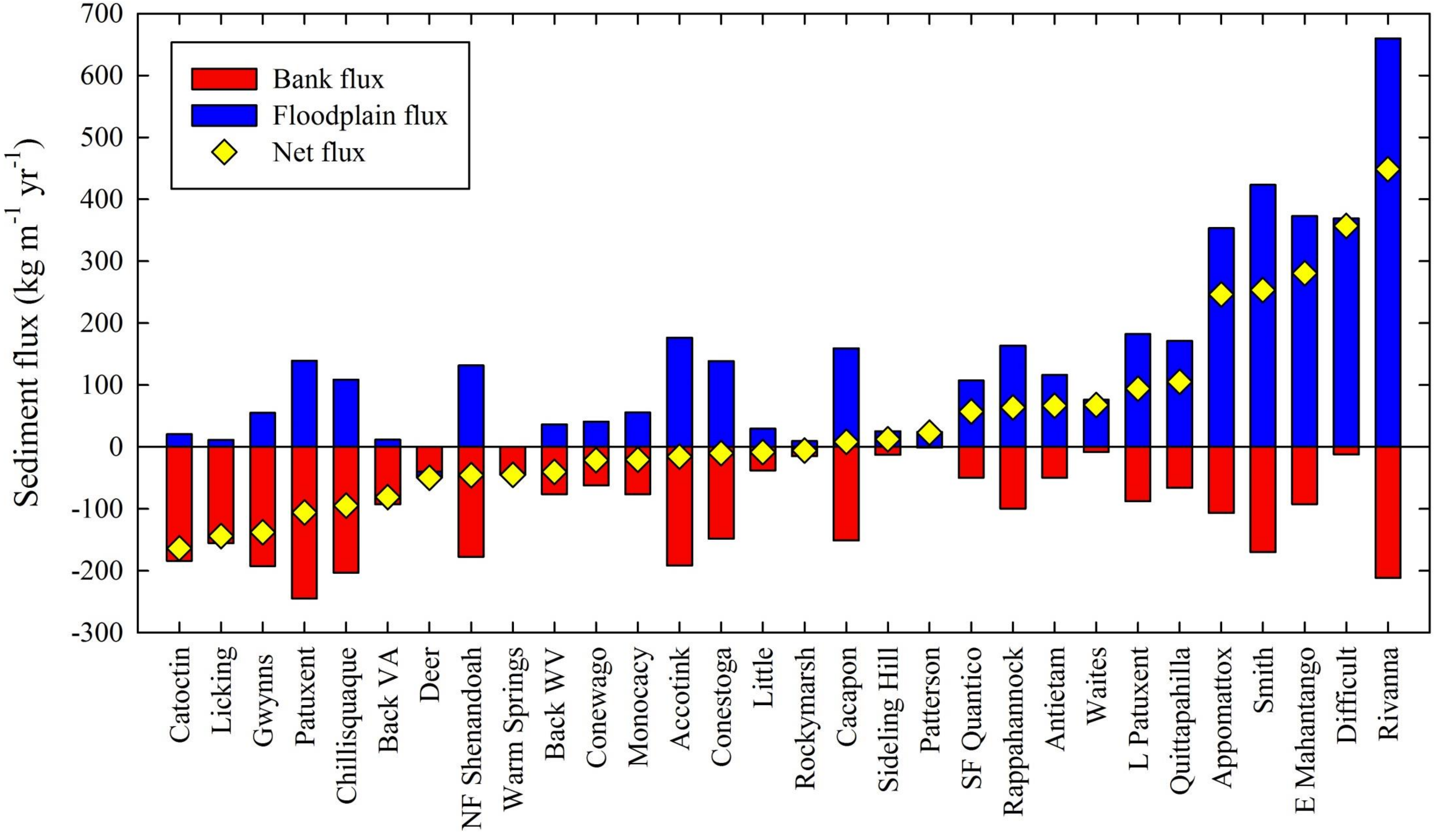


Scaling to the whole Chesapeake watershed: measuring and predicting bank and floodplain rates



USGS Chesapeake Floodplain Network: Valley/Ridge + Piedmont

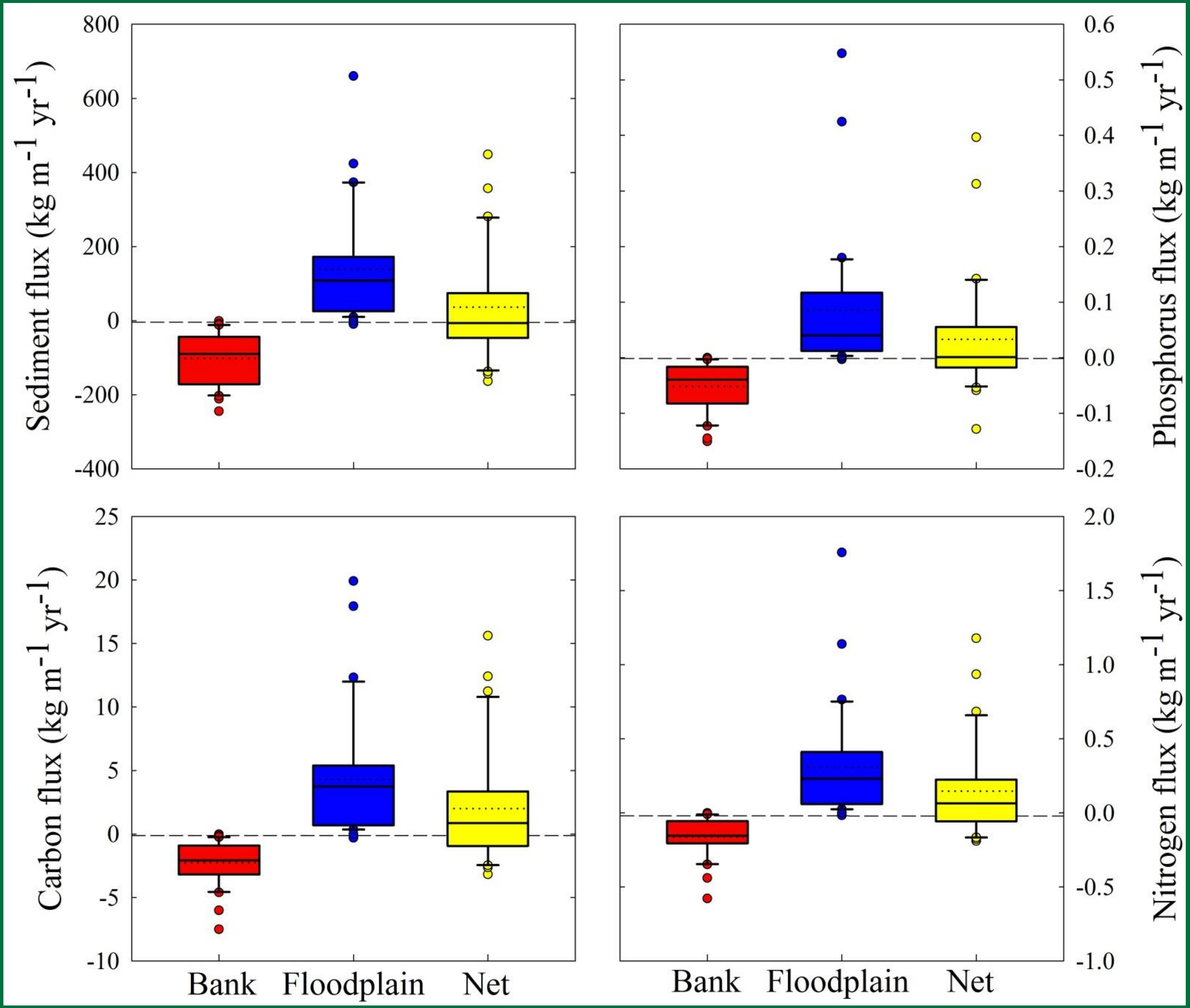
Some streams and rivers are strong sinks for sediments, N, and P;
most of watershed in 'equilbirium'



Ages of trees: floodplain = 45 yr, bank = 21 yr root exposed

USGS Chesapeake Floodplain Network: Valley/Ridge + Piedmont

Attached nutrient fluxes similar pattern as sediment fluxes



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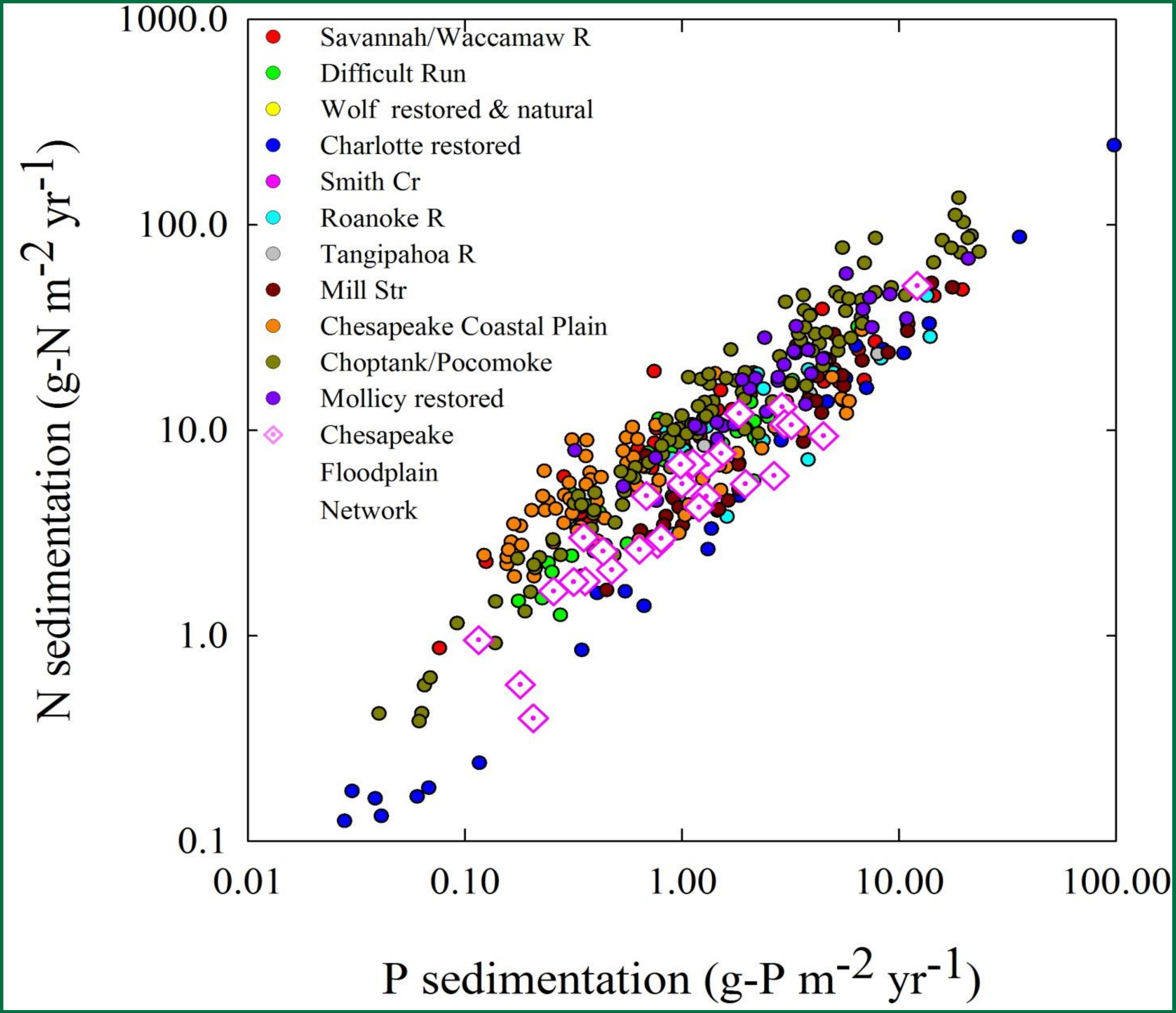
USGS Chesapeake Floodplain Network vs. other studies

Floodplain flux rates are typical



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Dynamic exchange of sediment + nutrients = hotspot

Gross floodplain trapping factor (Schenk et al. 2013):

	Avg.
Sed:	72
P:	40
N:	12

Kg m^{-2} yr^{-1} of floodplain
SPARROW yield estimates

Average hectare of floodplain traps 72X the sediment load generated by hectare of watershed

Indicator of importance to watershed loads

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Catchment + reach predictors of flux

Geomorphology, hydrology, land use, sediment, nutrients, …

Gages2

Area
Elevation median
Dimensionless elevation - relief ratio
Slope

Precipitation
Base Flow Index
Horton overland flow
Topographic wetness index
Subsurface flow contact time index
Soil permeability
Soil R-factor rainfall/runoff

Soil K-factor erodibility upper horizon
Dam density 2009
Dam storage 2009

Nitrogen fertilizer+manure application
Phosphorus fertilizer+manure application

NAWQA

% Developed 1974
% Developed 2012
% Production 1974
% Production 2012

Loads

SPARROW sed load
SPARROW P load
SPARROW N load
SPARROW sed yield
SPARROW P yield
SPARROW N yield

USGS NTN

Q50
Q90
Q99
Q50 yield
Q90 yield
Q99 yield

NLCD urban 2011
NLCD forest 2011
NLCD ag 2011
NLCD impervious 2006/2011

Reach Geomorphology (measured)

Floodplain width
Channel width
Bank height
Various ratios and products

NHD+

Reach sinuousity

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Fluxes are predictable (and can be extrapolated in GIS)

Stepwise multiple regressions:

Net Sediment Flux

P=0.005, R^2=0.44

Step	Beta	R^2 change	P
Constant			0.71
1. Channel depth	0.99	0.19	0.00
2. 1974 land use in production	-0.44	0.10	0.01
3. Channel width x depth	-0.53	0.09	0.07
4. Q99 yield	-0.28	0.07	0.09

Floodplain Sediment Flux

P<0.001, R^2=0.83

Step	Beta	R^2 change	P
Constant			0.00
1. Channel depth	1.36	0.36	0.00
2. Channel width x depth	-0.70	0.11	0.00
3. 1974 land use in production	-0.31	0.06	0.01
4. Reach sinuousity	0.29	0.06	0.02
5. Physiographic Province	1.04	0.05	0.00
6. Rainfall and Runoff R-factor (USLE)	0.75	0.05	0.00
7. Subsurface flow contact time index	-0.41	0.04	0.01
8. Channel width / floodplain width	-0.28	0.04	0.03
9. Median elevation	-0.26	0.03	0.07

Bank Sediment Flux

P<0.001, R^2=0.77

Step	Beta	R^2 change	P
Constant			0.31
1. Floodplain width	-1.62	0.35	0.00
2. Channel width / floodplain width	-0.61	0.23	0.00
3. P application rate	-0.58	0.05	0.00
4. Impervious landcover NLCD 2006/2011	0.45	0.11	0.00
5. Rainfall and Runoff R-factor (USLE)	0.43	0.03	0.00
6. Dam storage in watershed	-0.19	0.01	0.10

Net Nitrogen Flux

P<0.001, R^2=0.89

Step	Beta	R^2 change	P
Constant			0.00
1. Channel depth	1.94	0.25	0.00
2. Channel width x depth	-1.32	0.16	0.00
3. Reach sinuousity	0.56	0.15	0.00
4. Physiographic Province	0.90	0.08	0.00
5. 1974 land use in production	-0.32	0.09	0.00
6. Rainfall and Runoff R-factor (USLE)	0.59	0.08	0.00
7. Dam storage in watershed	-0.29	0.04	0.00
8. Horton overland flow %	-0.23	0.02	0.06
9. Floodplain width / channel width	-0.17	0.02	0.09

Floodplain Nitrogen Flux

P<0.001, R^2=0.92

Step	Beta	R^2 change	P
Constant			0.00
1. Channel depth	1.72	0.26	0.00
2. Channel width x depth	-1.29	0.15	0.00
3. Reach sinuousity	0.50	0.21	0.00
4. Physiographic Province	0.72	0.11	0.00
5. Floodplain width / channel width	0.27	0.07	0.01
6. Rainfall and Runoff R-factor (USLE)	0.56	0.03	0.00
7. SPARROW P yield	0.25	0.02	0.00
8. Soil permeability	0.45	0.04	0.00
9. Dam storage in watershed	-0.18	0.02	0.03
10. SPARROW Sediment load	0.16	0.02	0.07

Bank Nitrogen Flux

P<0.001, R^2=0.79

Step	Beta	R^2 change	P
Constant			0.10
1. P application rate	-0.96	0.25	0.00
2. Floodplain width	-1.45	0.10	0.00
3. Rainfall and Runoff R-factor (USLE)	0.53	0.18	0.00
4. Impervious landcover NLCD 2006/2011	0.60	0.12	0.00
5. Channel width / floodplain width	-0.56	0.06	0.00
6. Q50	0.25	0.03	0.04
7. Dam storage in watershed	-0.20	0.03	0.07

Net Phosphorus Flux

P<0.001, R^2=0.78

Step	Beta	R^2 change	P
Constant			0.00
1. Channel depth	2.02	0.25	0.00
2. Channel width x depth	-1.23	0.15	0.00
3. Reach sinuousity	0.45	0.09	0.00
4. Horton overland flow %	-0.57	0.10	0.00
5. Physiographic Province	0.52	0.07	0.00
6. Erodability K-factor (USLE)	0.47	0.07	0.01
7. 2011 land use in agriculture	-0.28	0.06	0.02

Floodplain Phosphorus Flux

P<0.001, R^2=0.72

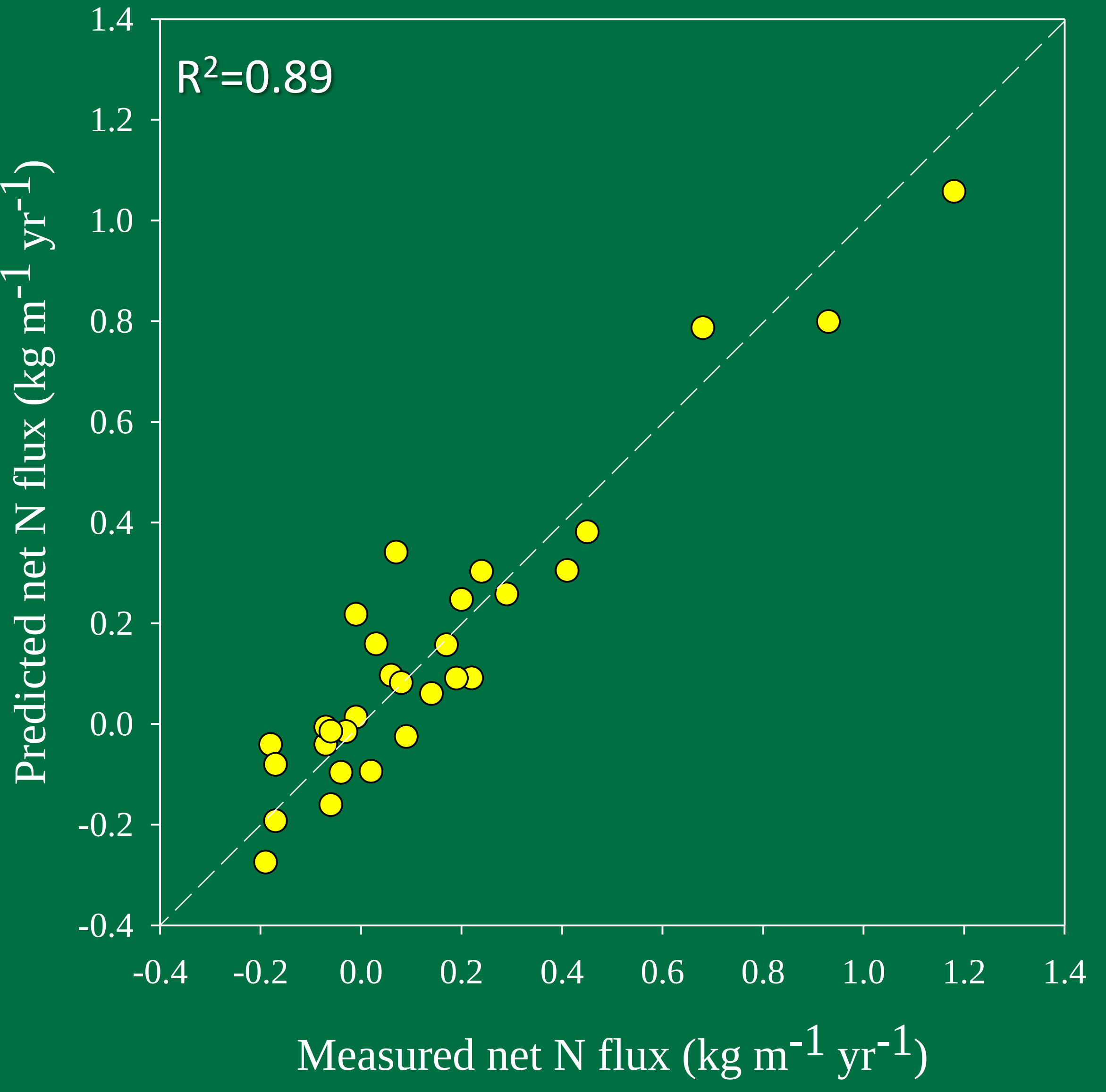
Step	Beta	R^2 change	P
Constant			0.00
1. Channel depth	1.66	0.38	0.00
2. Channel width x depth	-1.58	0.15	0.00
3. Reach sinuousity	0.35	0.08	0.01
4. Q50	0.50	0.07	0.02
5. Soil permeability	0.28	0.06	0.04

Bank Phosphorus flux

P<0.001, R^2=0.61

Step	Beta	R^2 change	P
Constant			0.03
1. 1974 land use in production	-0.29	0.38	0.04
2. Floodplain width	-0.58	0.13	0.00
3. Dimensionless median elevation - relief ratio	0.47	0.11	0.00

Predicting N flux associated with sediment in fluvial systems



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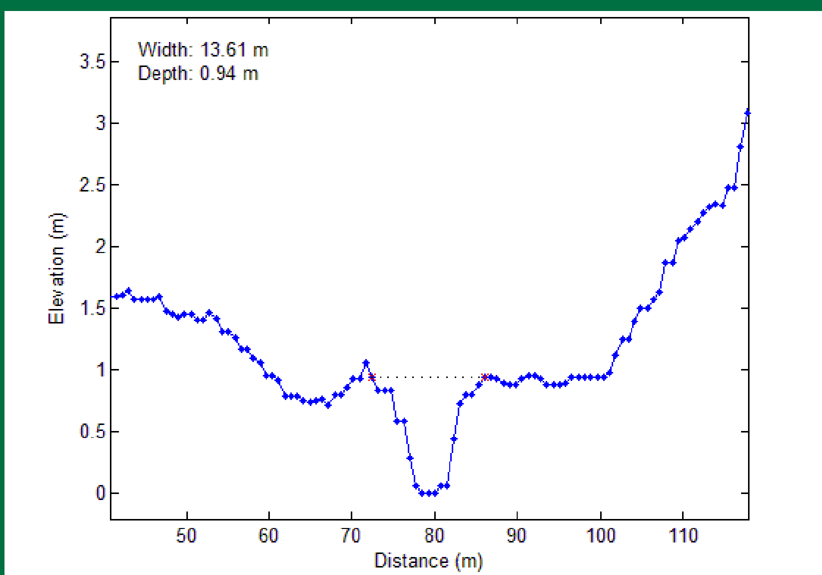
Predicting WQ processes: Difficult Run pilot

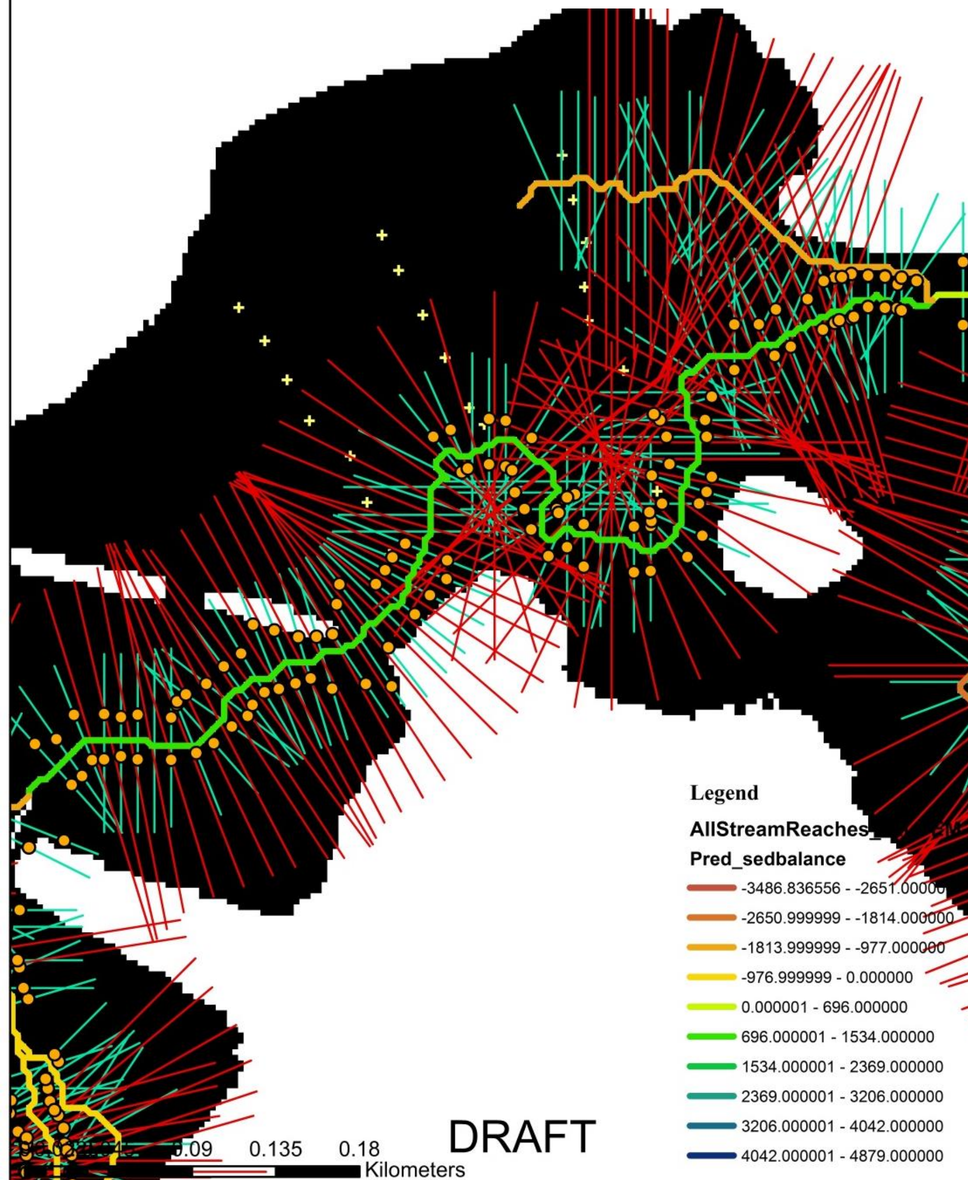
GIS tool for analyzing LiDAR
- -floodplain width
- -bank height
- -channel width

Sam Lamont, WVU
Peter Claggett, USGS

Example 1-m DEM x-section profile



Implementation of GIS x-sections
@ Leesburg Pike



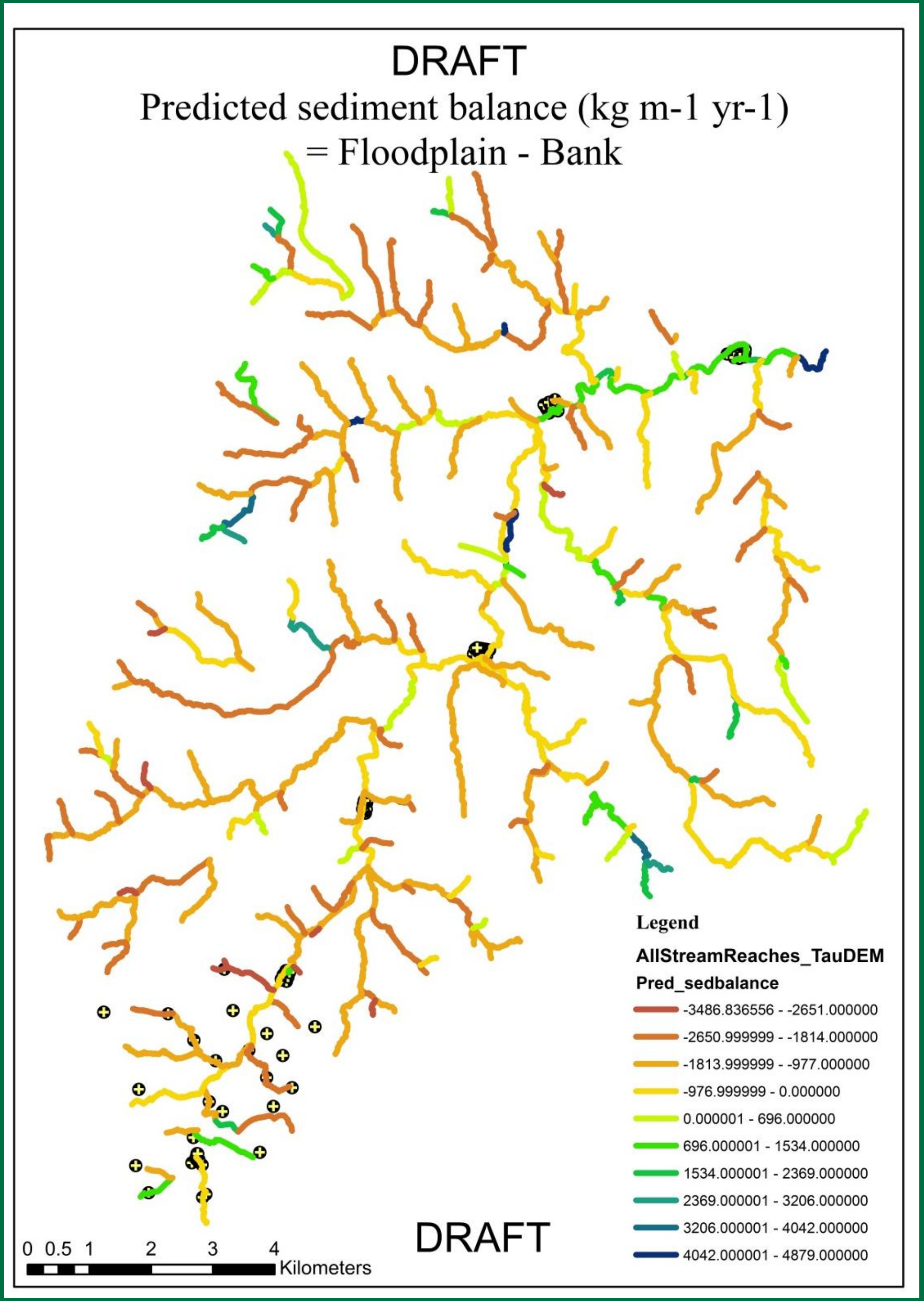
Predicting WQ processes: Difficult Run pilot

<u>Regression</u>

Mainstem X-section net sediment balance predicted (R^2=0.57, P=0.007) by:

- Channel width
- Floodplain elevation range

DRAFT!
Tool in refinement



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USGS Chesapeake Floodplain Network

- We can measure and model if streams and rivers are sinks for sediment and associated particulate N and P over long time scales
- The Chesapeake watershed is mostly in 'equilibrium' for sediment fluvial exchange; but some floodplains are strongly depositional
- Fluxes of sediment and nutrients were similar in Valley & Ridge and Piedmont physiographic provinces, indicating limited control of regional geology over alluvial sediment exchange.
- Measured rates of floodplain depositional flux of N and P were typical of the Mid-Atlantic and Southeastern U.S.
- Regional floodplain, bank, and net fluxes of sediment and nutrients were predictable using a combination of reach geomorphology and watershed characteristics (all of which could be estimated in GIS).
- Floodplains are hotspots in the landscape for sediment and nutrient sinks and sources, influencing river loads to the Chesapeake Bay

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We can measure and predict the important role of floodplain sediment exchange in Chesapeake watersheds

Morgan Creek, MD

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USGS Chesapeake Floodplain Network

What's next:

1. Measurement of Coastal Plain long-term fluxes
2. Refinement of predictive statistics
    1. Alternatives to stepwise regression
    2. Inclusion of NTN measured loads
3. Further development of GIS geomorphic tool
    1. Better estimate active floodplain width
    2. Difficult Run pilot to develop predictive tool
    3. Apply to all of Chesapeakia
4. Apply GIS geomorphic tool + catchment GIS
    1. Predict long-term fluxes for all of Chesapeakia
    2. Calculate mass-balance 'budget' of stream flux vs. load
5. Measure contemporary fluxes 3-yr post installation and repeat

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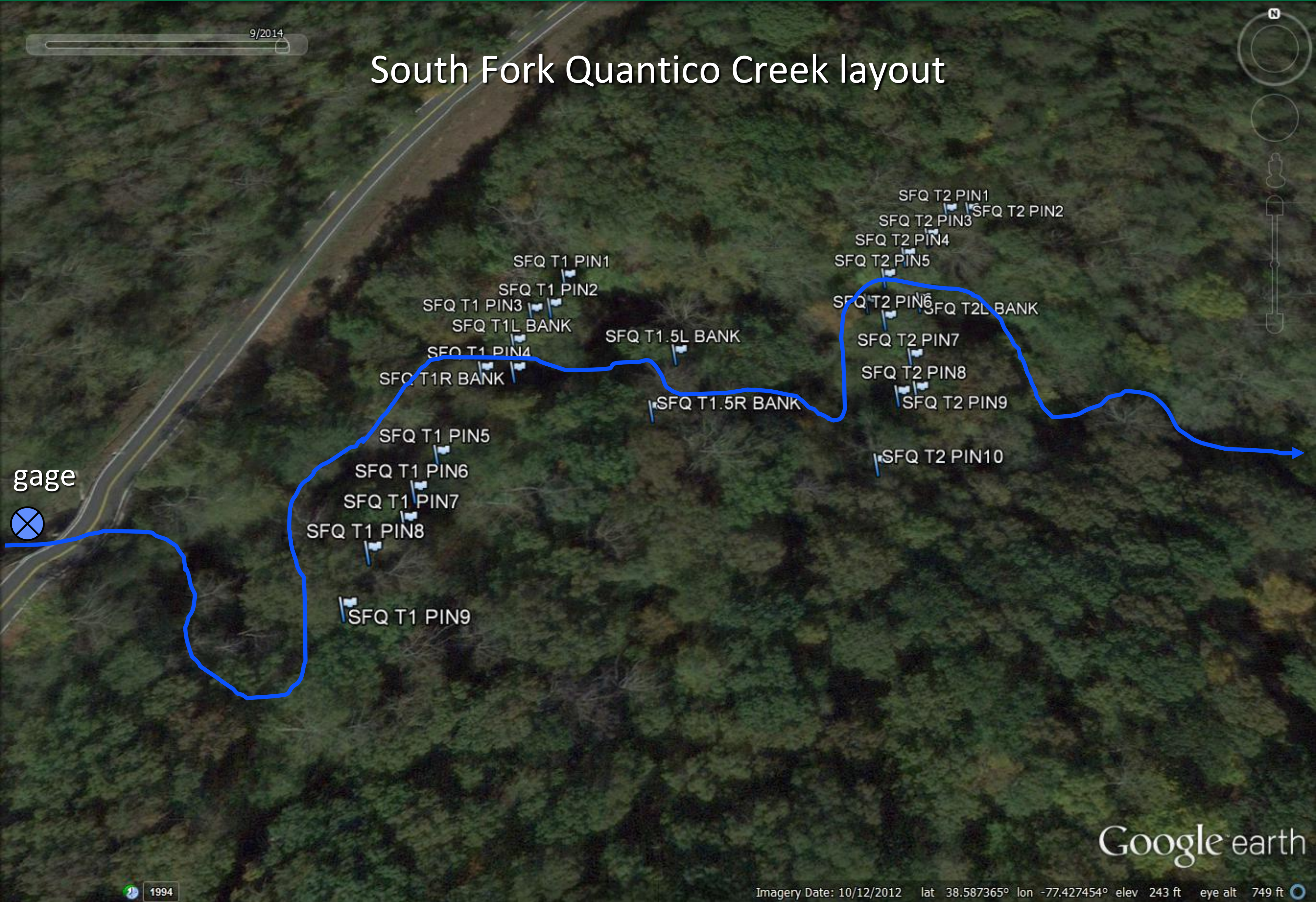
USGS Chesapeake Floodplain Network: example site



USGS Chesapeake Floodplain Network

Comparison of Physiographic Provinces

Floodplain, bank, and net fluxes of sediment, C, N, and P were similar (P>0.14)

	Piedmont > Valley & Ridge	***Piedmont = Valley & Ridge***	***Valley & Ridge > Piedmont***
Geomorphology	Bank height (m) Floodplain width (m) Floodplain width : bank height Floodplain width : channel width	Channel ○ Width (m) ○ Width X channel depth (m^2)	Channel ○ Bed d50 (mm) ○ Width : channel depth
Floodplain	Sediment ○ Mg (mg g^{-1}) ○ K (mg g^{-1}) ○ Al (mg g^{-1}) ○ Fe (mg g^{-1}) ○ Ti (mg g^{-1})	Age of trees (yr) Vertical accretion rate (cm yr^{-1}) Sediment ○ Bulk density (g cm^{-3}) ○ Bulk density < 1-mm (g cm^{-3}) ○ mineral content (%) ○ carbonate content (%) ○ organic C (%) ○ N (%) ○ P (mg g^{-1}) ○ Ca (mg g^{-1}) ○ Na (mg g^{-1})	
Bank	Bank eroding (%) Sediment ○ bulk density (g cm^{-3}) ○ Mg (mg g^{-1}) ○ K (mg g^{-1}) ○ Al (mg g^{-1}) ○ Fe (mg g^{-1}) ○ Ti (mg g^{-1})	Adjusted erosion rate (cm yr^{-1}) Sediment ○ bulk density < 1-mm (g cm^{-3}) ○ mineral content (%) ○ carbonate content (%) ○ P (mg g^{-1}) ○ Ca (mg g^{-1}) ○ Na (mg g^{-1})	Age of tree roots (yr) Sediment ○ organic C (%) ○ N (%)

Reach geomorphology and sediment physicochemistry differed between the Valley & Ridge and Piedmont physiographic provinces for many measurements, but fluxes did not differ.

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Statistical approach:

1. Regression modeling of predictors of reach flux (sed, N, P) using measured variables, watershed attributes, and GIS analysis of DEM

2. Chesapeake channel-floodplain geomorphic GIS.

3. Combine #1 and #2 to create a) maps of reach-scale magnitude of bank erosion, floodplain deposition, and net sediment balance; and b) scaled-up mass of net sediment balance relative to NTN measured loads.

Even if #3 is not possible (either #1 not statistically significant or #2 not possible), we still will have measured contemporary and long-term bank erosion, floodplain deposition, and net sediment balance and fundamental floodplain characteristics for a very wide range of settings (45 reaches!) in the Chesapeake watershed that will fundamentally transform understanding of WQ processes and solutions

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Goal:

Measure and predict the sediment/N/P balance of streams and rivers (sink or source of floodplain and banks) in entire Chesapeake watershed

USGS Chesapeake Floodplain Network

Reach (site) scale empirical estimates:

Contemporary (3-yr):

- Reach-scale sediment and associated N, P, and C bank erosion
- Reach-scale sediment and associated N, P, and C floodplain deposition
- Reach-scale sediment and associated N, P, and C balance (bank vs. floodplain)
- Floodplain trapping factor

Long-term (age of trees):

- Reach-scale sediment and associated N, P, and C bank erosion
- Reach-scale sediment and associated N, P, and C floodplain deposition
- Reach-scale sediment and associated N, P, and C balance (bank vs. floodplain)
- Floodplain trapping factor

Channel-floodplain hydrogeomorphology:

- Channel width, bank height, floodplain width, channel slope; soil/sediment/bed particle size, bulk density, organic content; floodplain inundation history

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