How to model sediment and nutrient fluxes of floodplains and streambanks across the Chesapeake watershed

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U.S. Department of the Interior
U.S. Geological Survey

Understanding and scaling transport processes thru watersheds

Alluvial sediment exchange

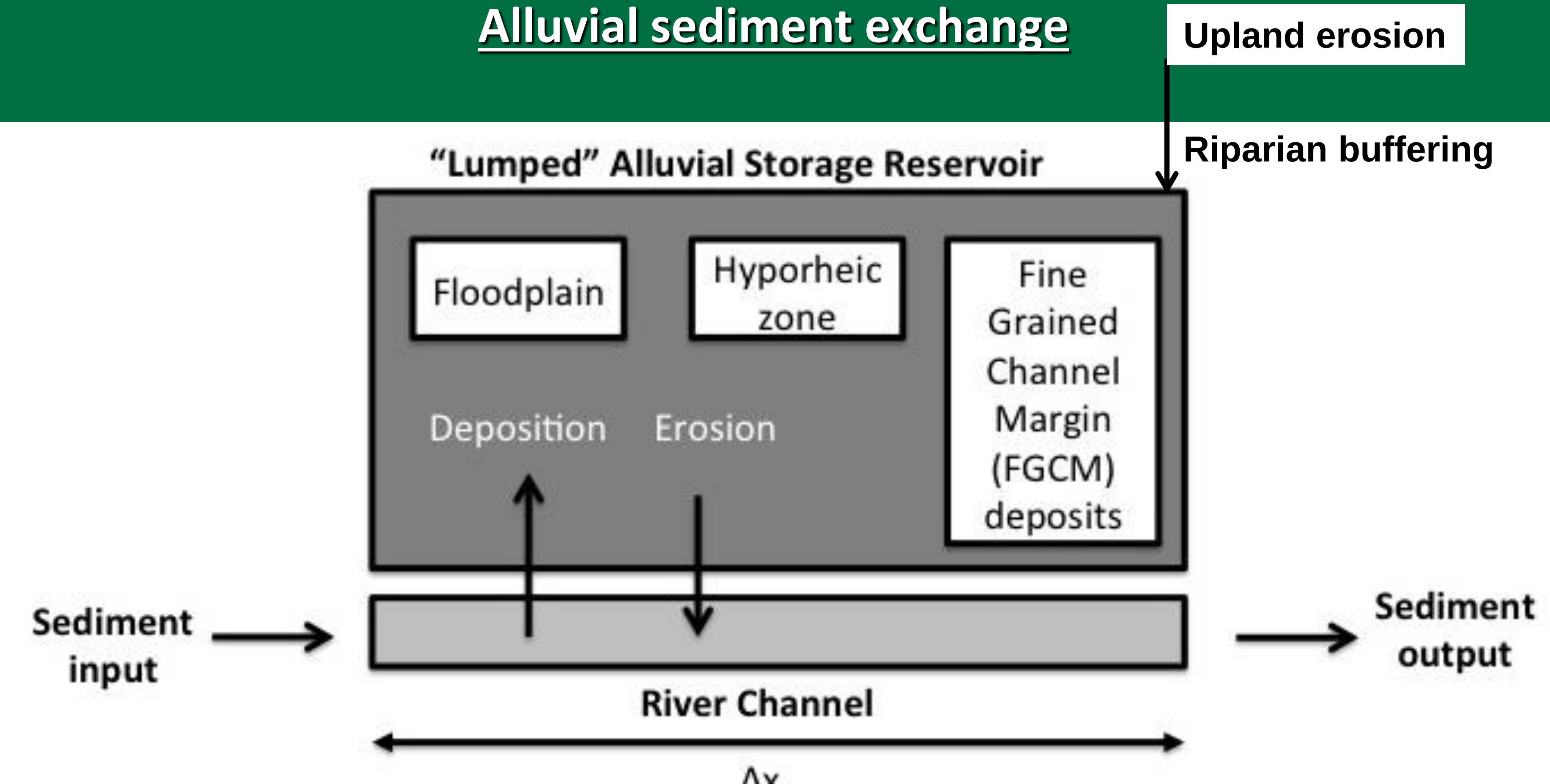

Figure 1. Spatial structure (in plan view) of a 1-dimensional "valley-averaged" suspended sediment routing model.

Modified from Benthem and Skalak

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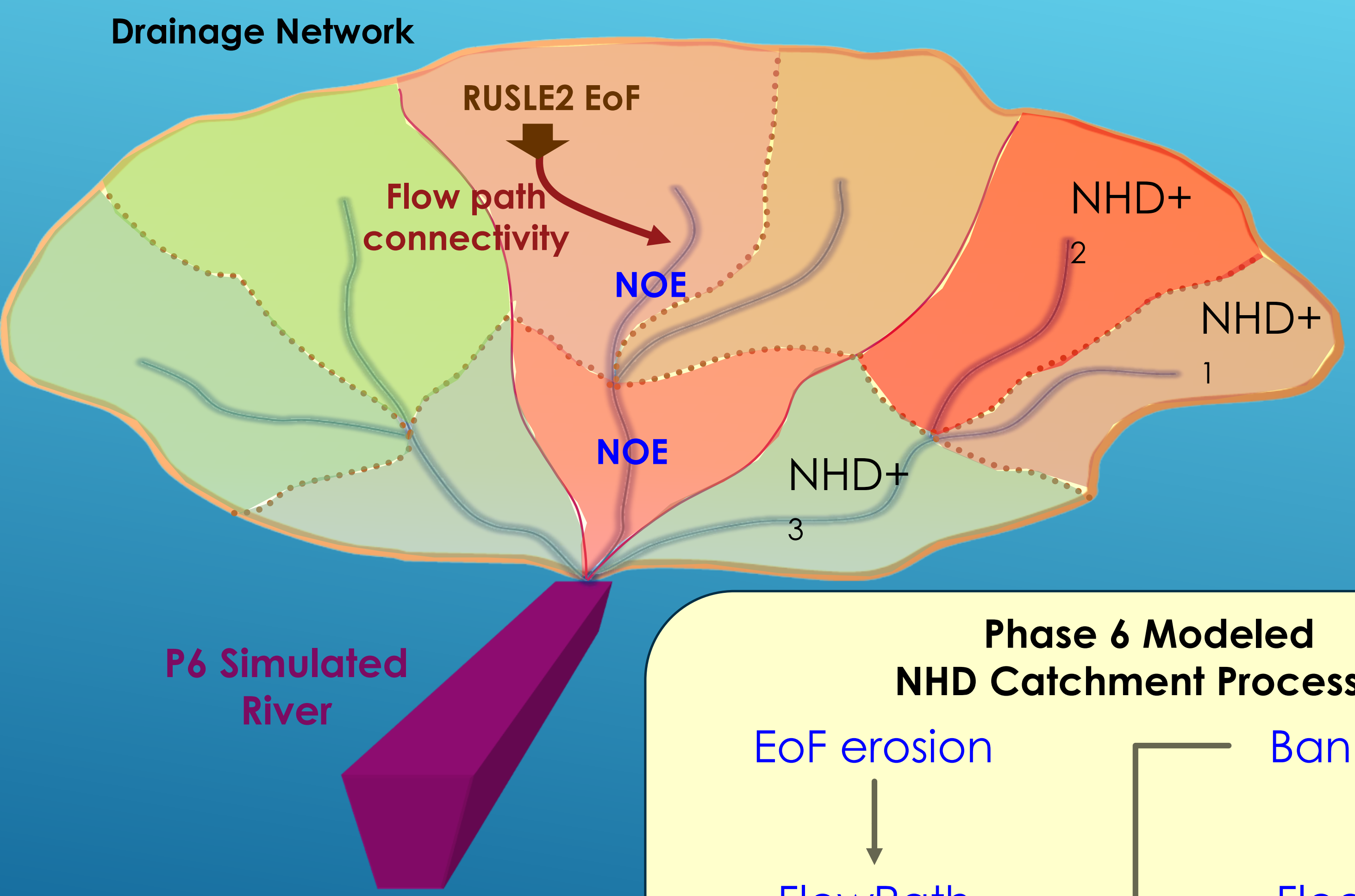
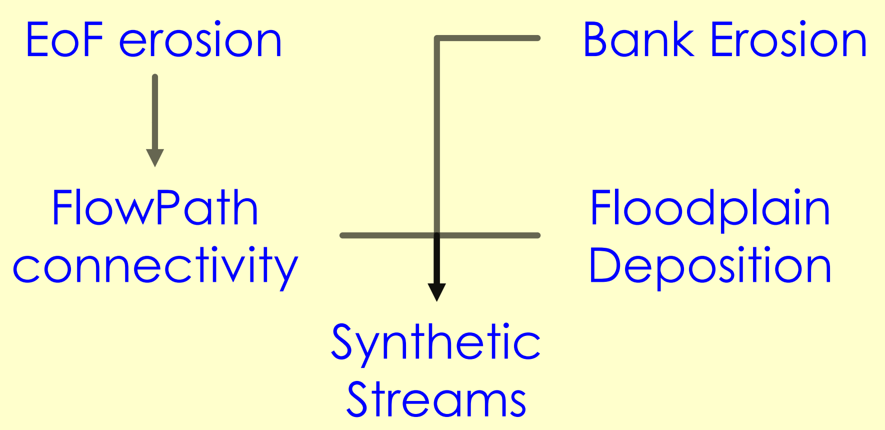
79% of P load and 28% of N load to Chesapeake Bay is particulate (Noe and Hupp 2009, from Langland et al. 2006)

Sediment Delivery to Simulated Rivers

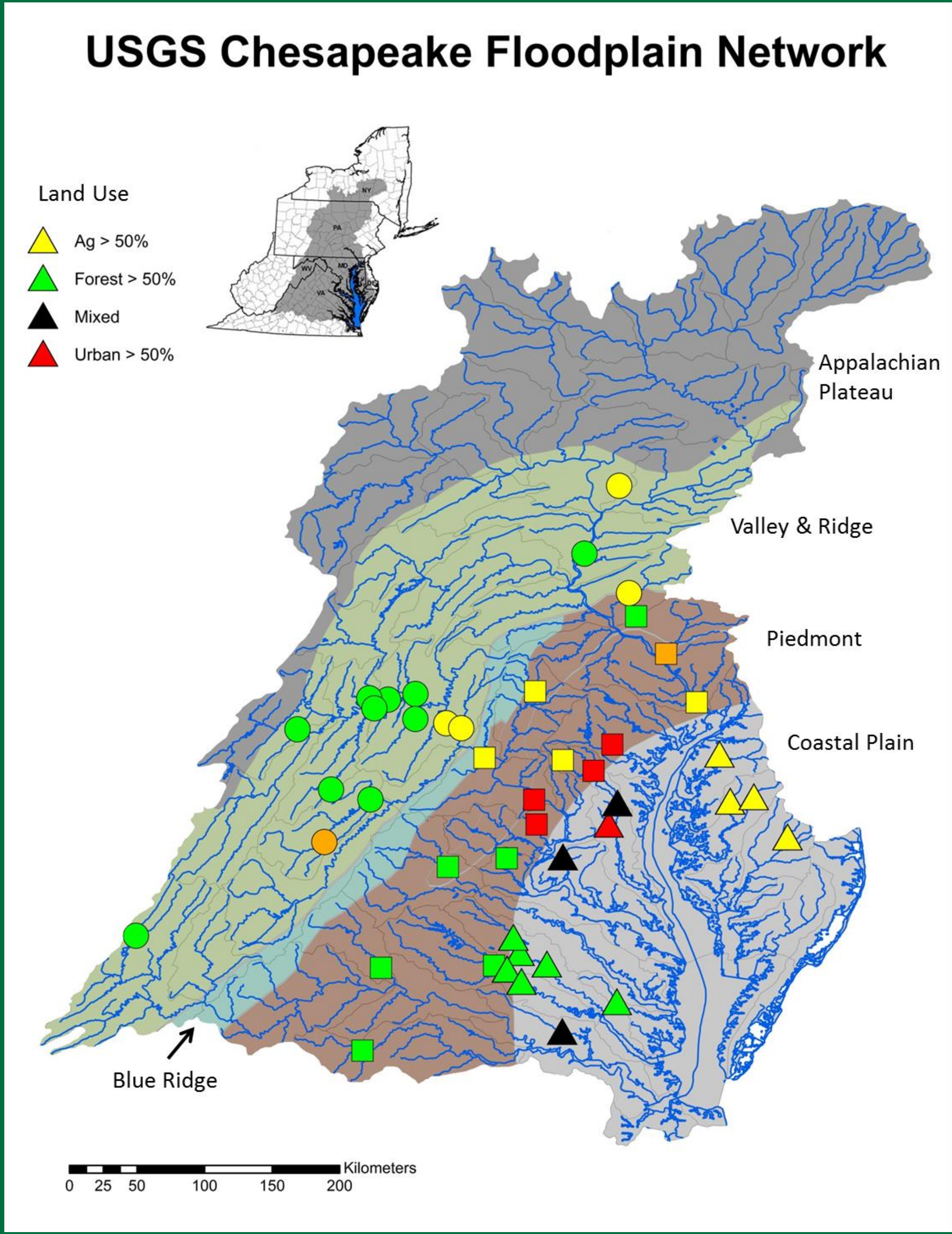


Phase 6 Modeled
NHD Catchment Processes



The next leap: The USGS Chesapeake Floodplain Network

Goal:
Measure and predict the sediment/N/P fluxes of bank erosion and floodplain deposition 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

Status:

- Valley&Ridge and Piedmont finished
- Coastal Plain 13 of 15 measured, data analysis complete by January 2016

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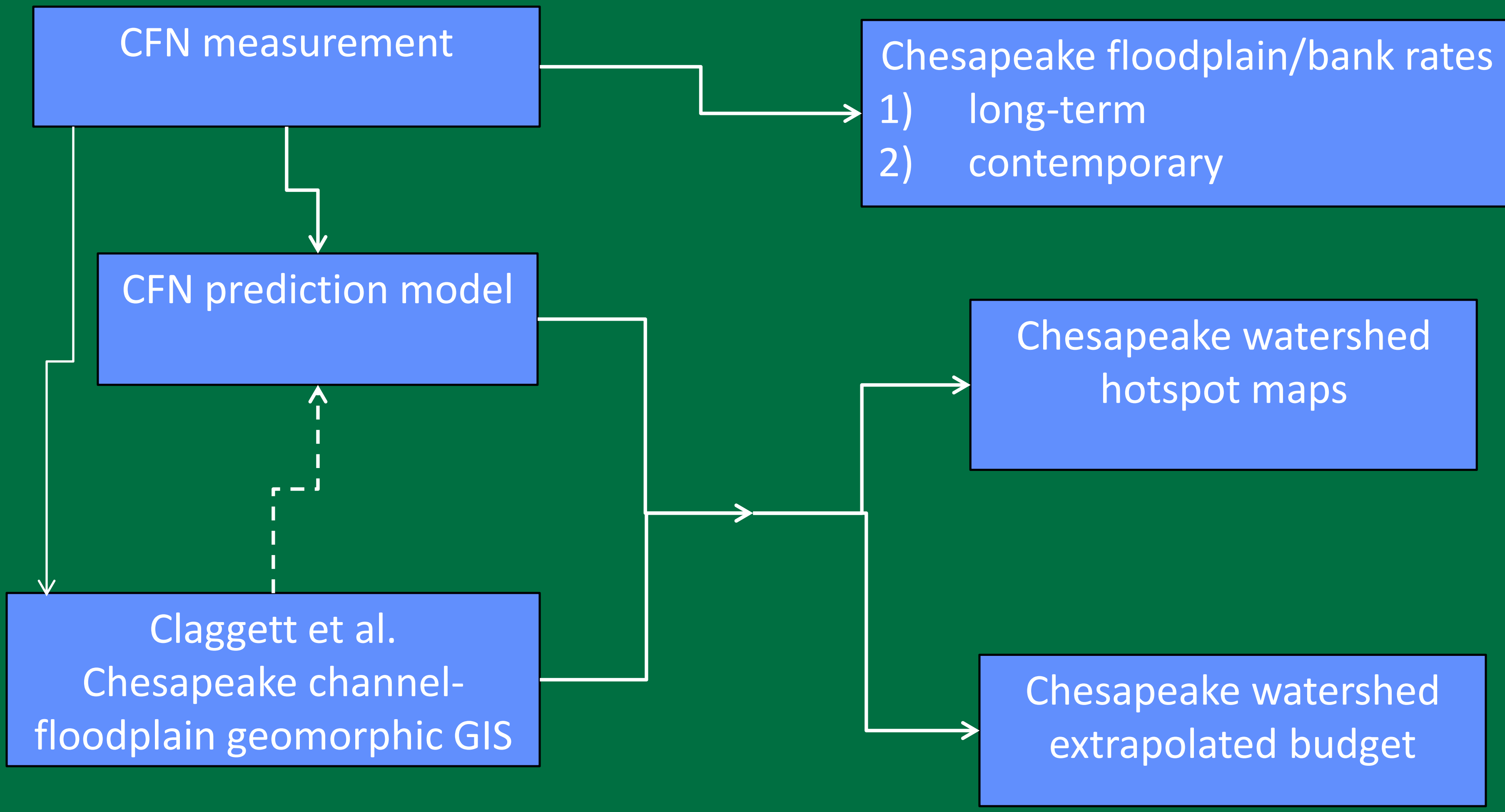
Scaling to the whole Chesapeake watershed: measuring and predicting bank and floodplain rates

Steps | **Products**



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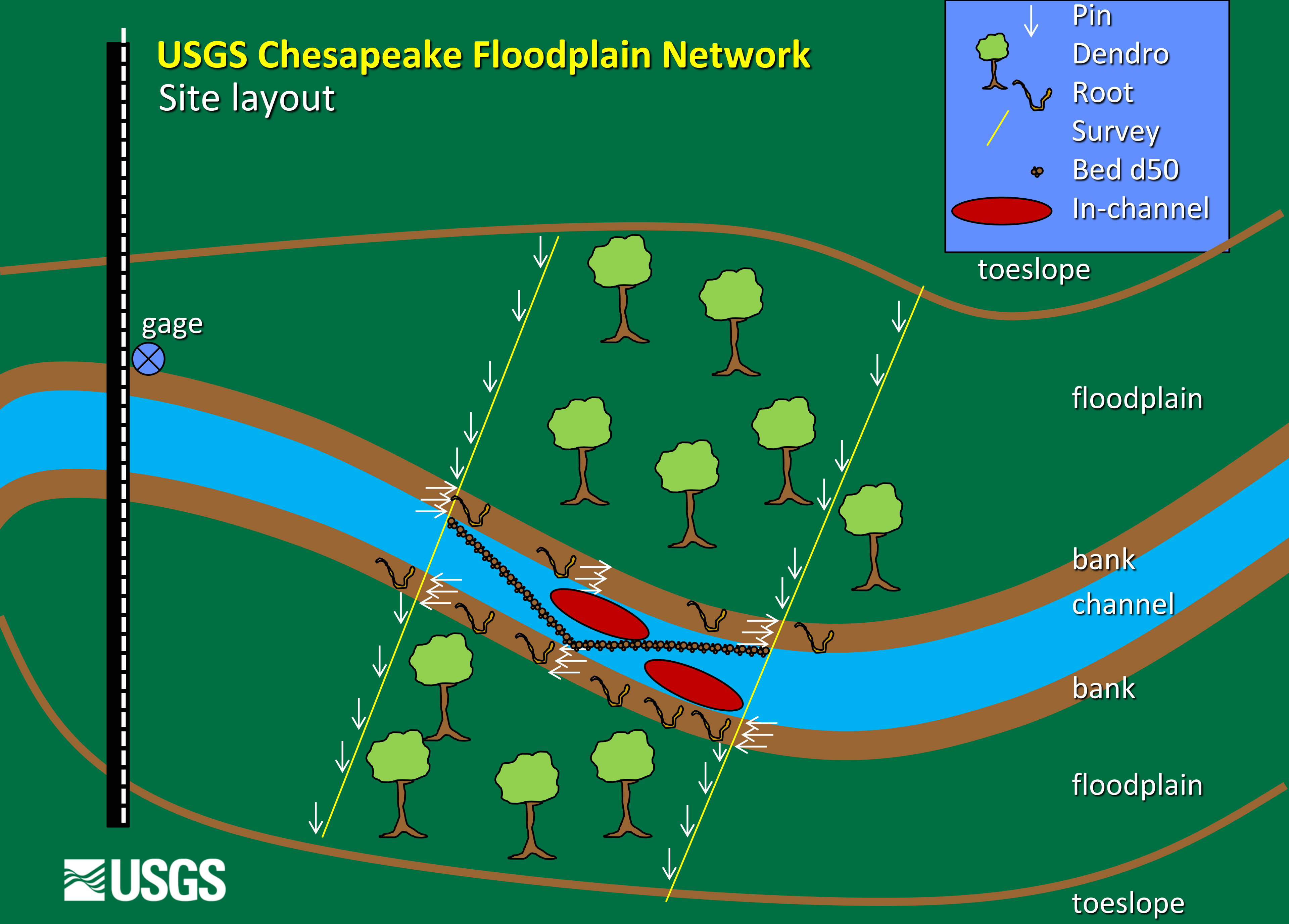
USGS Chesapeake Floodplain Network

Site layout



USGS Chesapeake Floodplain Network

Measurements:

Sediment budget terms (45 sites)
Contemporary (pin) floodplain and bank flux
Long-term (dendro) floodplain and bank flux
In-channel sediment storage volumes

Geomorphic measurements (45 sites)
X-section survey (channel, banks, floodplain)
Longitudinal survey (tie to gage, reach slope)
Channel bed particle size

Biogeochemistry (45 sites)
Soil/sediment TN, TP, TOC, LOI, particle size
Soil/sediment biogeochemical processes

Age Distributions (6 sites)
In-channel (bomb radiocarbon, Be-7, Pb-210)
Floodplain (Be-7, Pb-210, OSL, radiocarbon)

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Dendrogeomorphic method

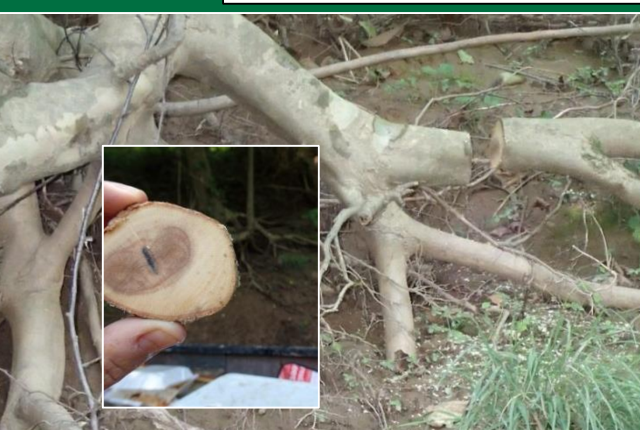
Flux calculations:

$g\ m^{-1}\ yr^{-1}$

Floodplain: vertical change rate * bulk density * total floodplain width
($m\ yr^{-1}$) ($g\ cm^{-3}$) (m)

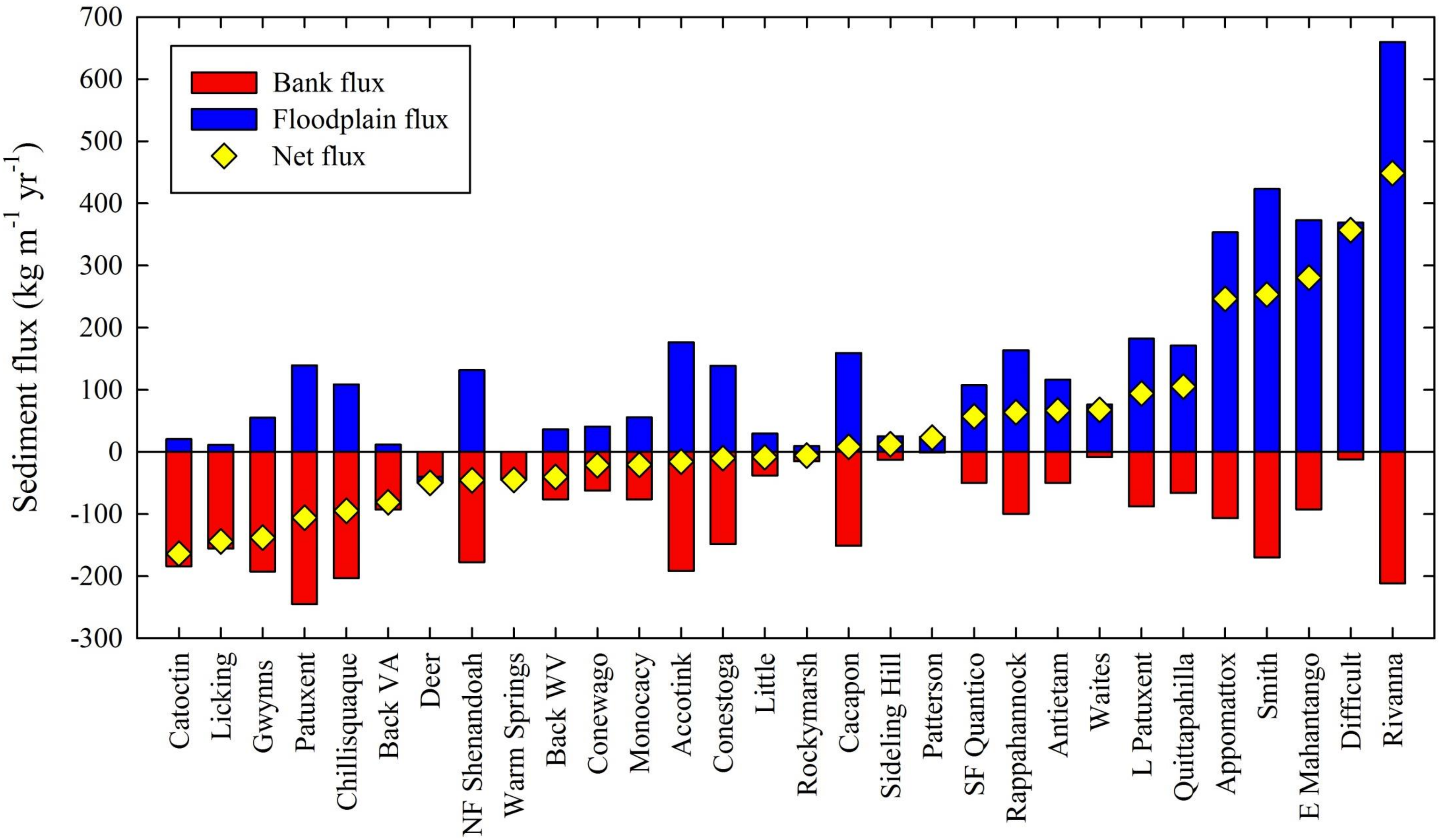
Bank: lateral change rate * bulk density * bank height * 2 * correction

Net balance: Floodplain flux – Bank flux



USGS Chesapeake Floodplain Network: Valley/Ridge + Piedmont

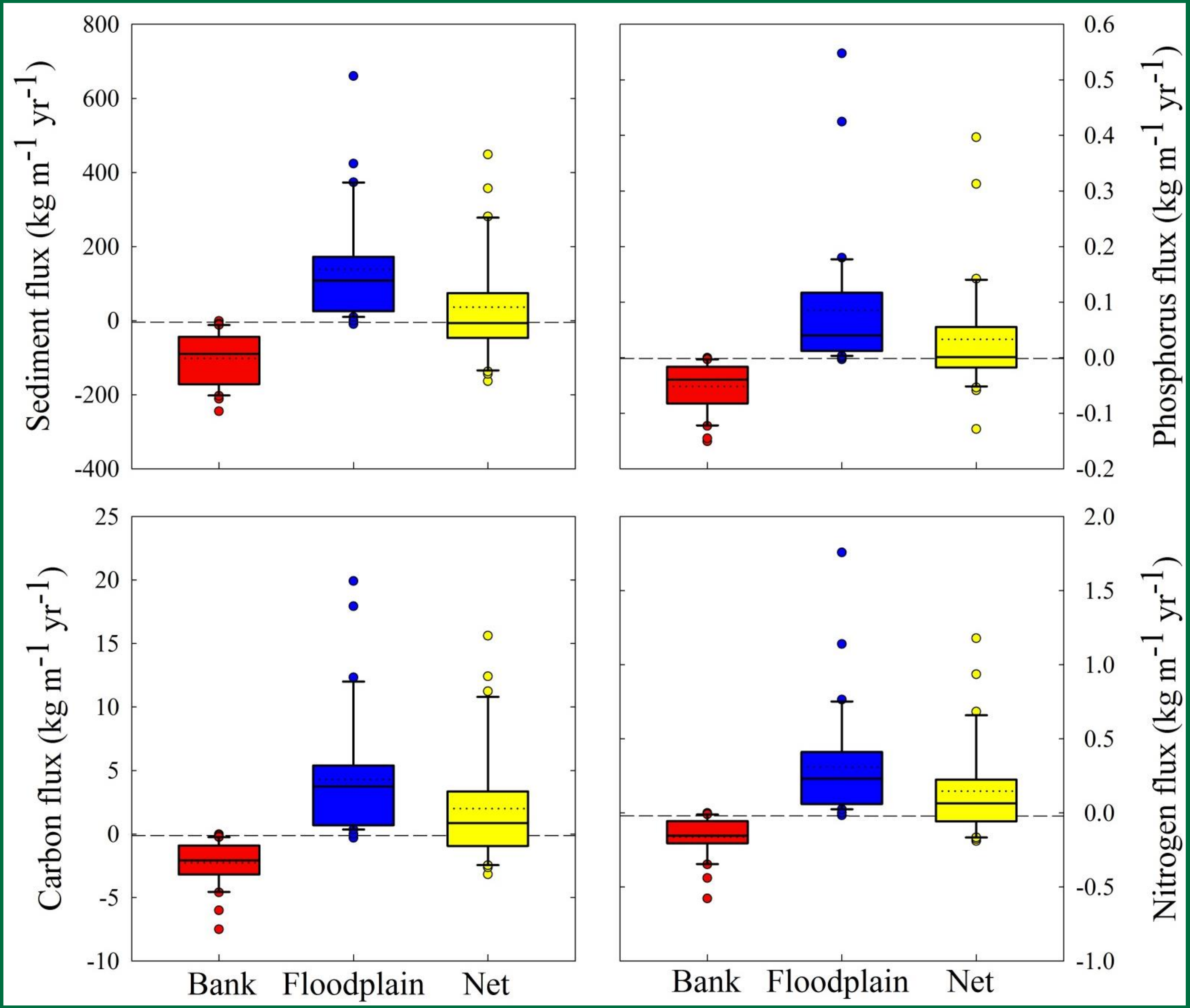
Some streams and rivers are strong sinks for sediments, N, and P; most of watershed in 'equilbirium'



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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Catchment + reach predictors of flux

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

Watershed characteristics
- Topography
- Geology
- Climate
- Hydrology
- Land use
- Soils
- Nutrient application
- River load
- Geomorphology

Reach geomorphology
- Floodplain
- Bank
- Channel

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Catchment + reach predictors of flux

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:

Set of predictors	Statistics		Fluxes		
			Net sediment balance	Floodplain sediment flux	Bank sediment flux
Geomorphology only	P-to-enter <0.05	R^2	0.15	0.54	0.35
		Predictors	1. Bank Height	1. Channel width ÷ Floodplain width 2. Bank height	1. Floodplain width
	P-to-enter <0.10	R^2	0.15	0.54	0.41
		Predictors	1. Bank Height	1. Channel width ÷ Floodplain width 2. Bank height	1. Floodplain width 2. Channel width
Watershed only	P-to-enter <0.05	R^2	0.23	0.20	0.00
		Predictors	1. Dam #	1. Dam #	None
	P-to-enter <0.10	R^2	0.23	0.20	0.22
		Predictors	1. Dam #	1. Dam #	1. Stream power index (Q50) 2. Forest land-use 2011
Geomorphology + Watershed	P-to-enter <0.05	R^2	0.23	0.72	0.57
		Predictors	1. Dam #	1. Channel width ÷ Floodplain width 2. Bank height 3. Physiographic province 4. Production land-use 2012	1. Floodplain width 2. Elevation-Relief Ratio 3. Channel width ÷ Floodplain width
	P-to-enter <0.10	**R^2**	**0.53**	**0.76**	**0.77**
		Predictors	1. Dam # 2. Channel width ÷ Floodplain width 3. Floodplain width ÷ Bank height 4. Elevation-Relief Ratio	1. Channel width ÷ Floodplain width 2. Bank height 3. Physiographic province 4. Production land-use 2012 5. K factor	1. Floodplain width 2. Channel width ÷ Floodplain width 3. P application 4. Impervious 2006/2011 5. R factor 6. Dam storage

Chesapeake Geomorphic GIS toolkit: Calculated metrics

Fluvial Geomorphic Metrics:

- Bank height
- Bank angle
- Channel width
- Channel profile slope
- Floodplain elevation range
- Floodplain width
- Floodplain profile slope
- Drainage area

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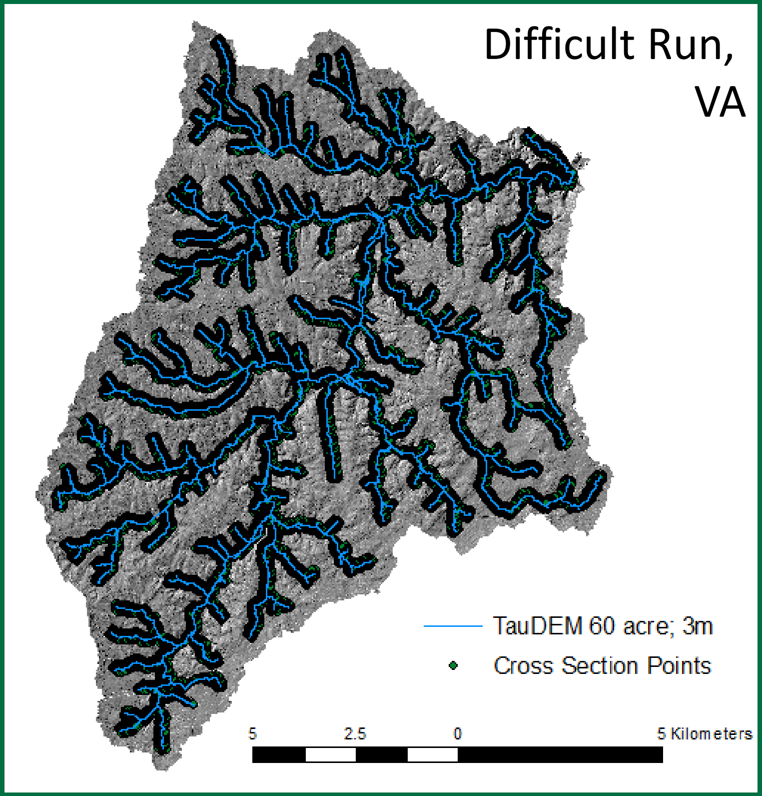
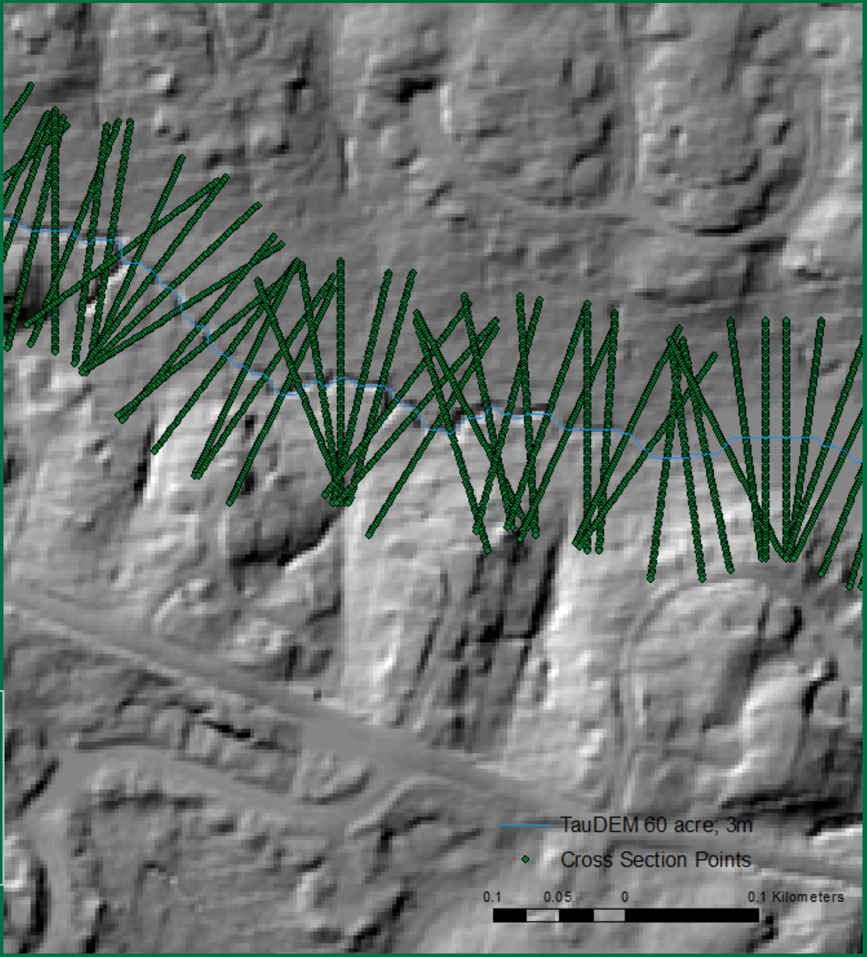
Chesapeake Geomorphic GIS toolkit: Cross-section implementation





Can vary:

- Linear fit length, spacing, width, point spacing
- Width limited to catchment boundary

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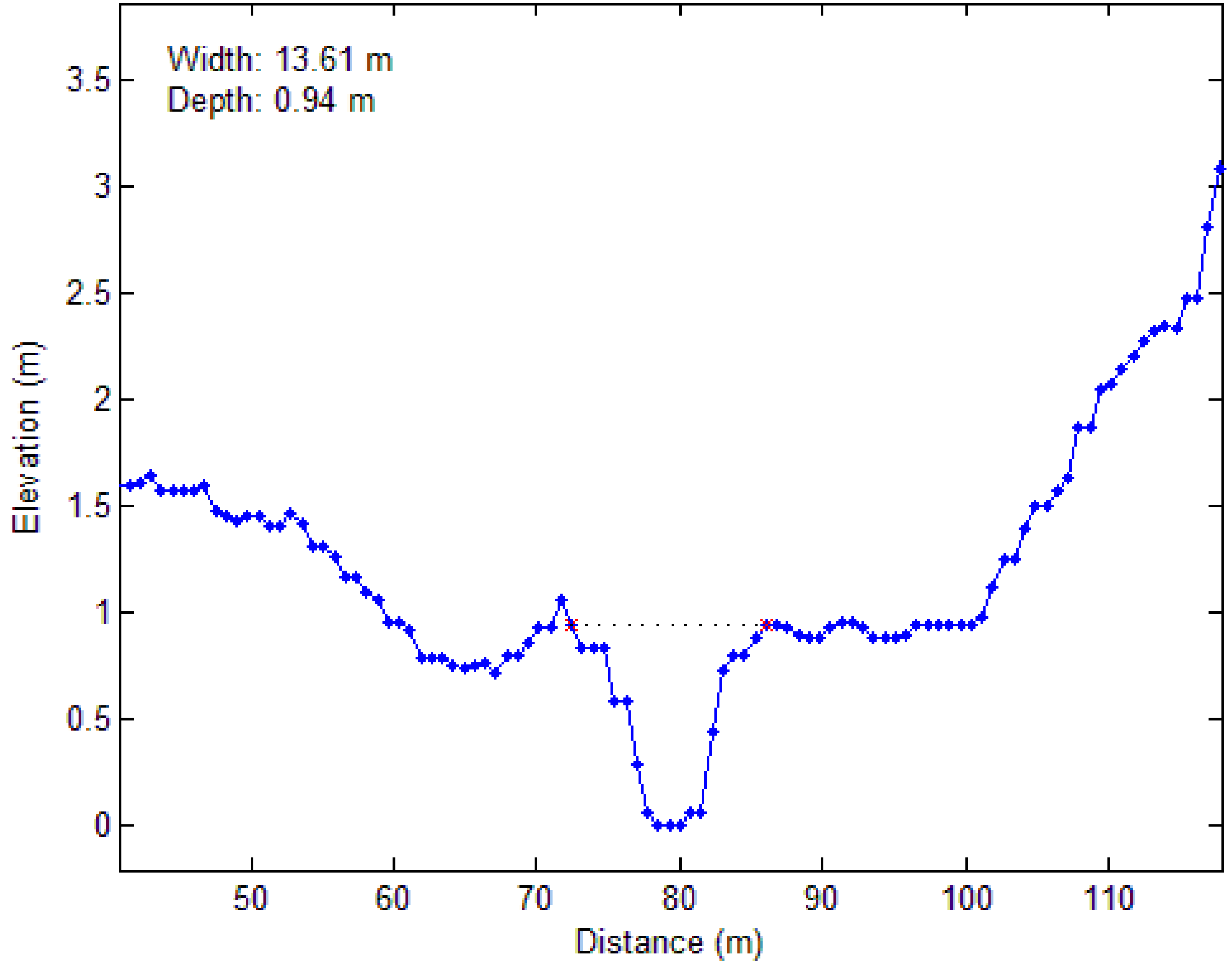
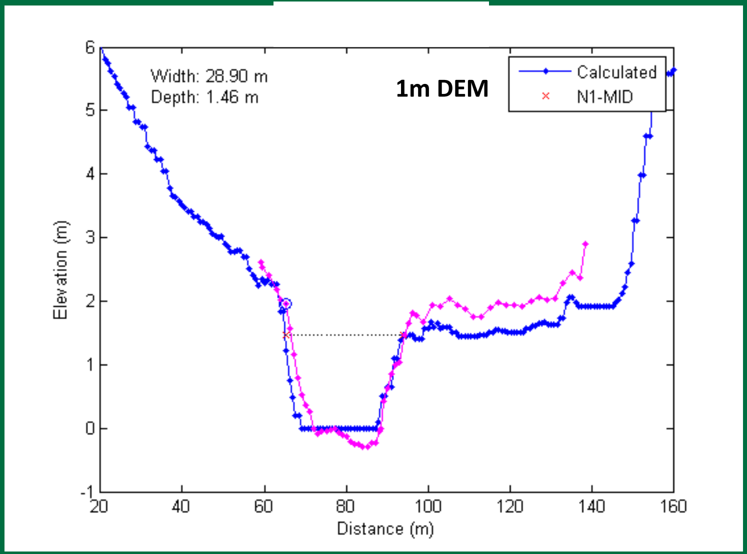
Chesapeake Geomorphic GIS toolkit: Channel x-section delineation

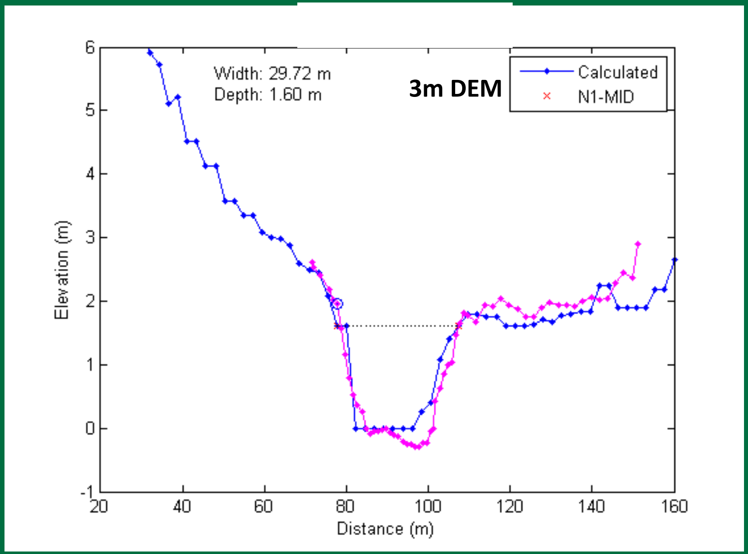
Bank locations based on slope breaks

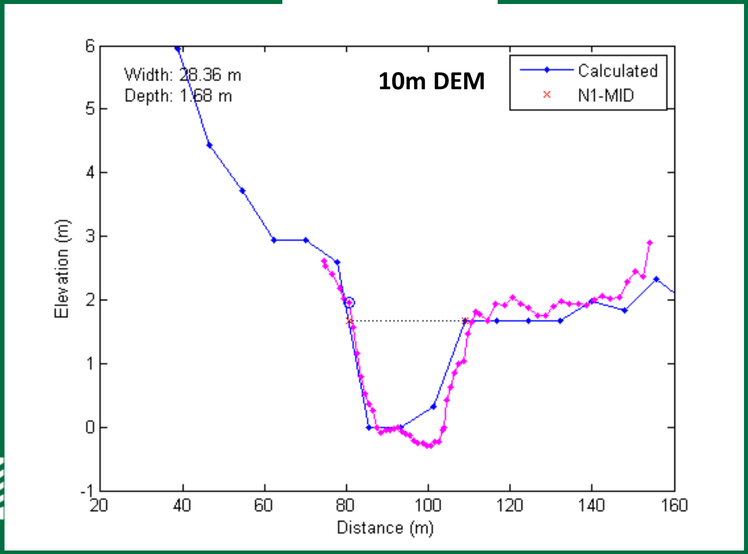


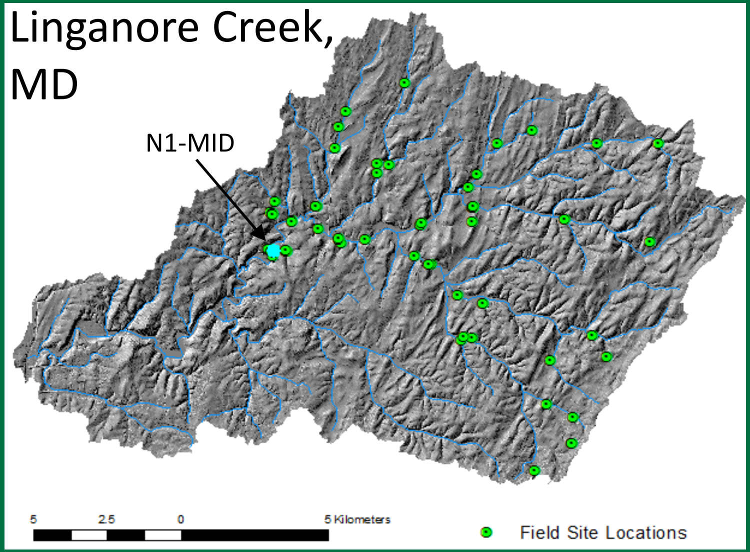
Chesapeake Geomorphic GIS toolkit: Bank identification

Chesapeake Geomorphic GIS toolkit: Comparison with field x-sections

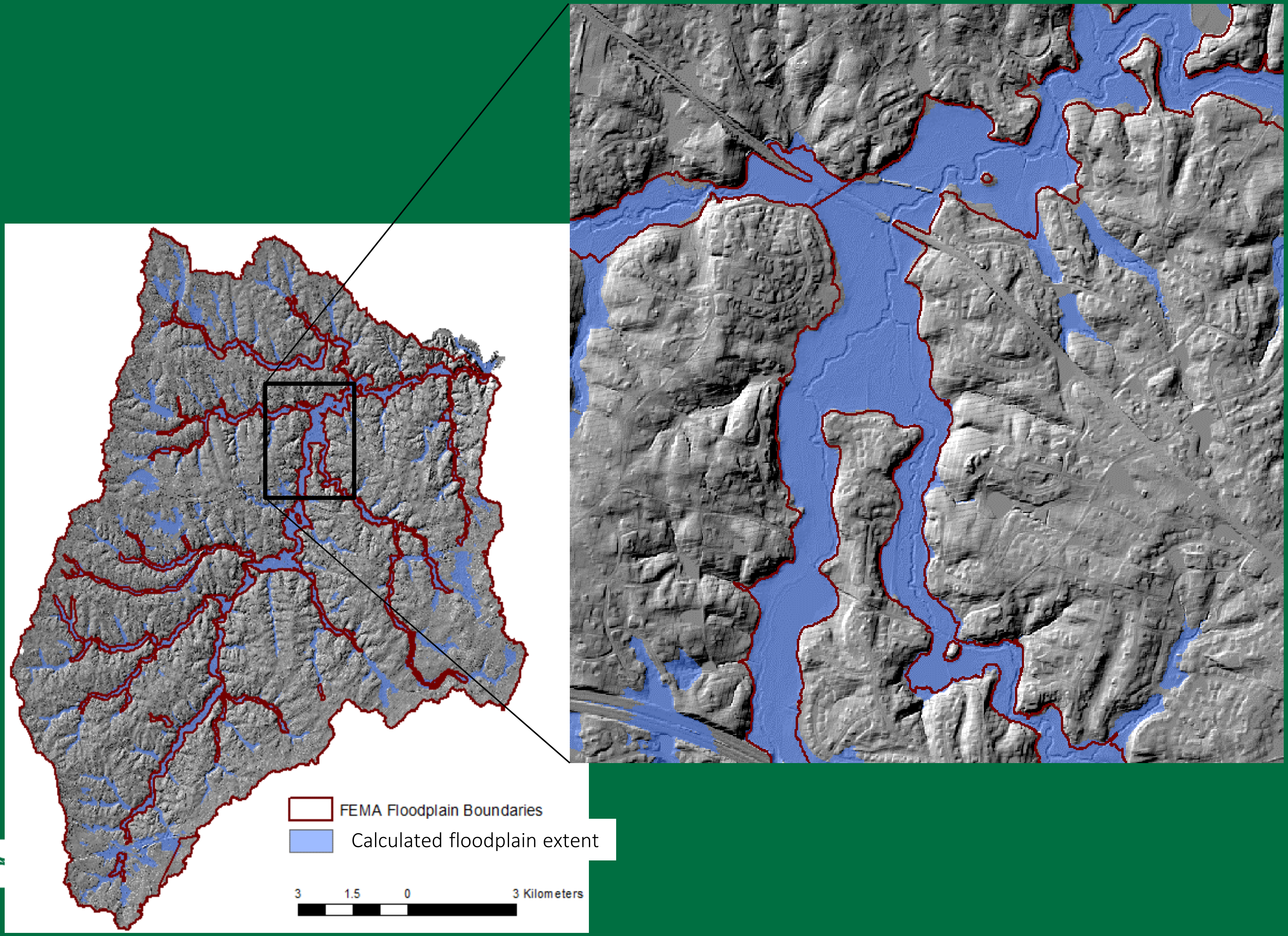








Chesapeake Geomorphic GIS toolkit: Floodplain delineation

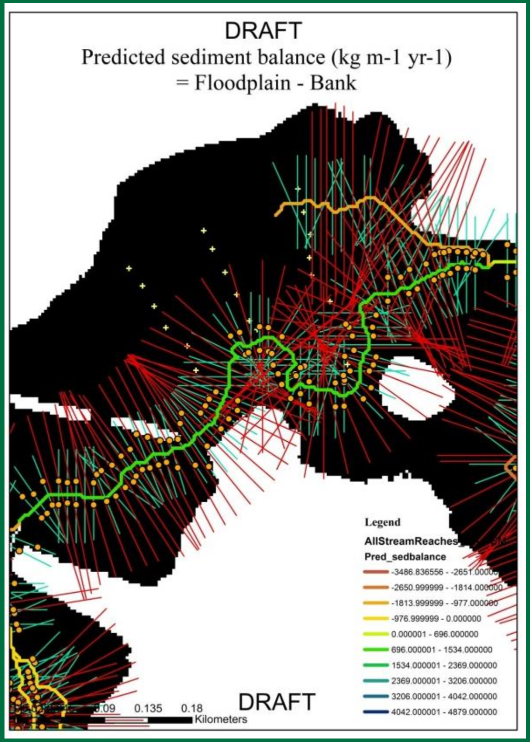


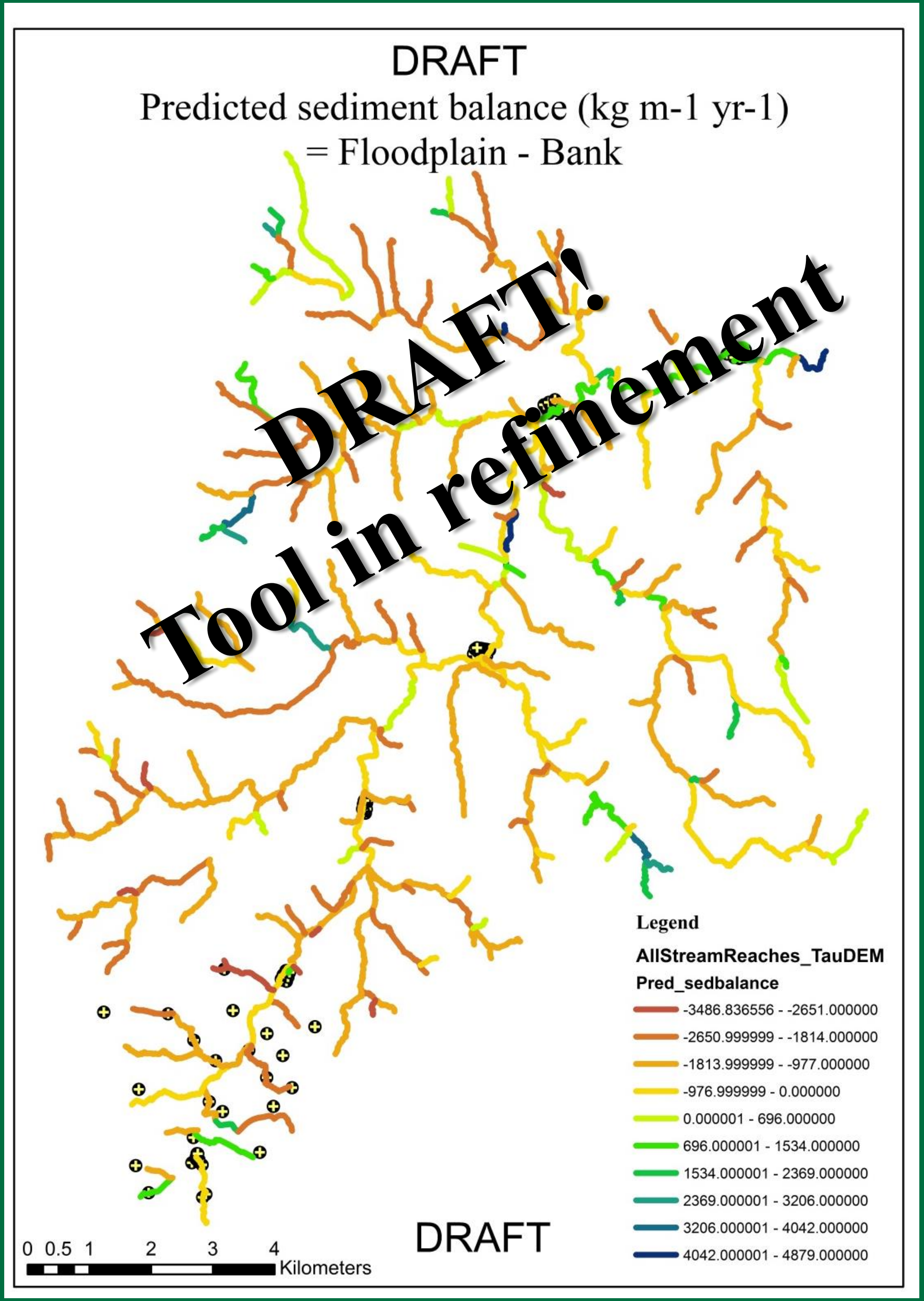
Predicting WQ processes: Difficult Run pilot

Regression

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

- Channel width
- Floodplain elevation range





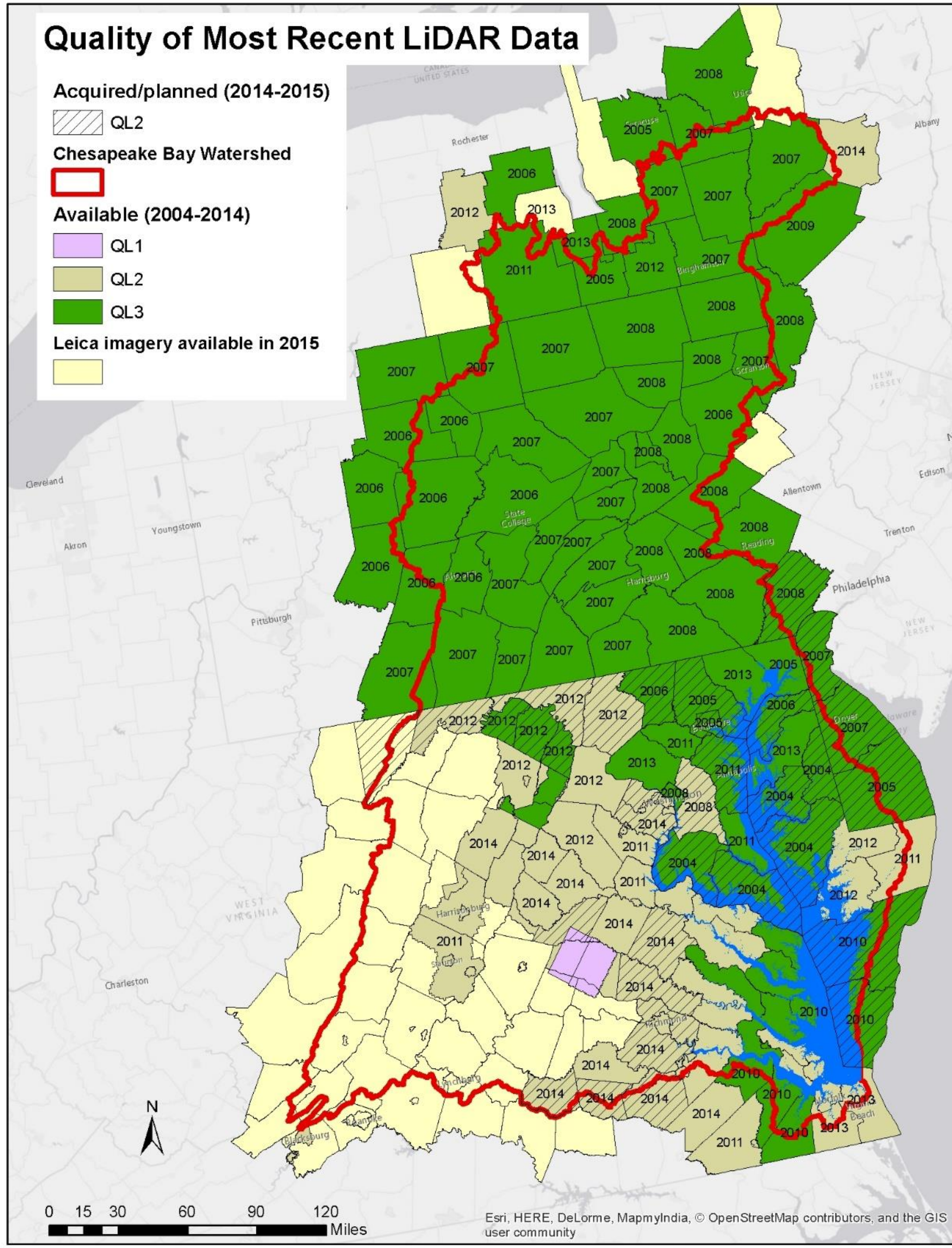
Predicting WQ processes: LiDAR availability

~ 80% of Chesapeake watershed has available LiDAR

Coastal Plain analyzed by Spring 2016

Shenandoah Valley LiDAR available and completed Spring 2016

Remaining SW VA/WV planned September 2016



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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.

- Chesapeake GIS toolkit and database should be valuable tool for additional research on transport processes and stream condition and health.

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USGS Chesapeake Floodplain Network

What's next:	Completed:
1. Validate GIS geomorphology (VR & PIED) using field geomorphology.	Nov 2015
2. Calculation of Coastal Plain long-term fluxes.	Dec 2015
3. Regress VR & PIED fluxes using GIS geomorphology.	Dec 2015
4. GIS geomorphology database ready (VR & PIED)	Jan 2016
5. GIS geomorphology database complete (~90%; CP and Shenandoah added).	Apr 2016
6. Regress VR & PIED & CP fluxes using GIS geomorphology + watershed characteristics.	Apr 2016
7. Extrapolate bank and floodplain sediment fluxes to all of VR & PIED & CP 1. Summed by NHD+ catchment 2. Maps by reach of fluxes	May 2016
8. Add SW VA and WV LiDAR gap (100% of watershed complete)	Jan 2017
9. Measure contemporary fluxes 3-yr post installation and repeat.	2019

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Fluxes are predictable (and can be extrapolated in GIS)

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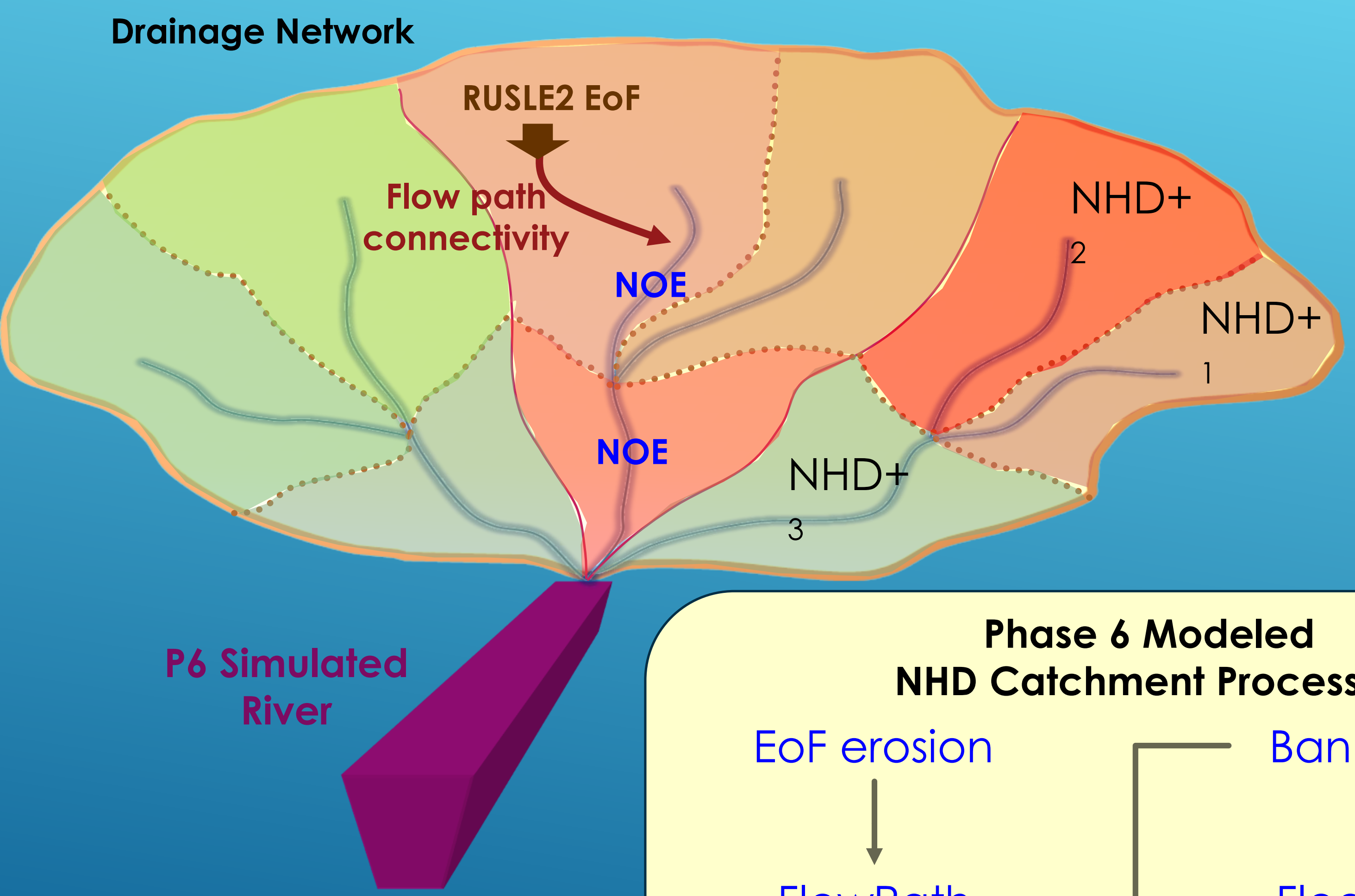
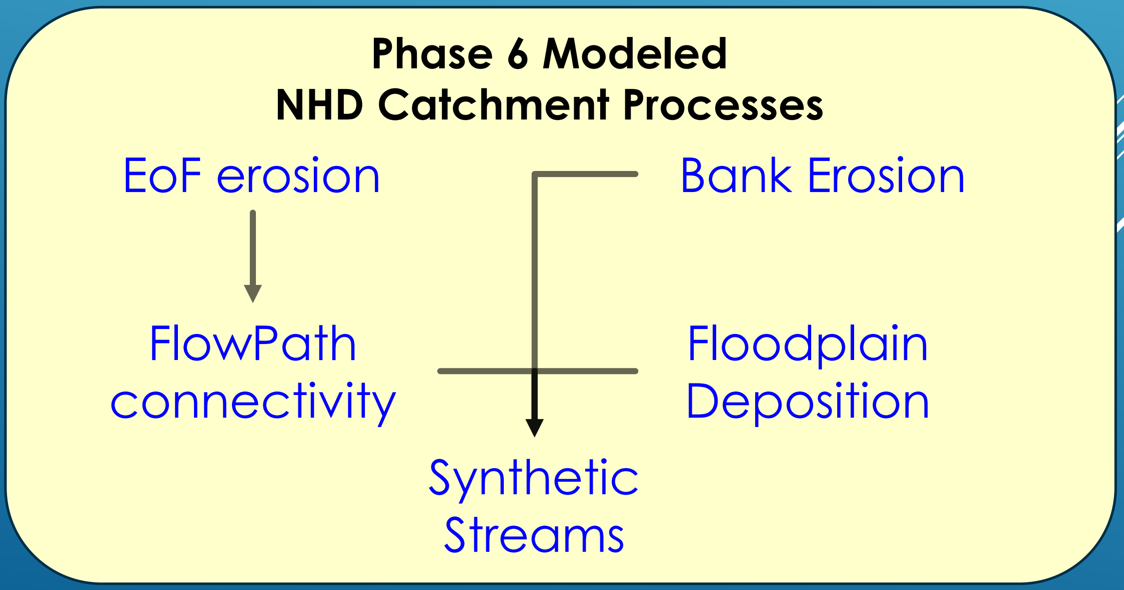
Sediment Delivery to Simulated Rivers





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

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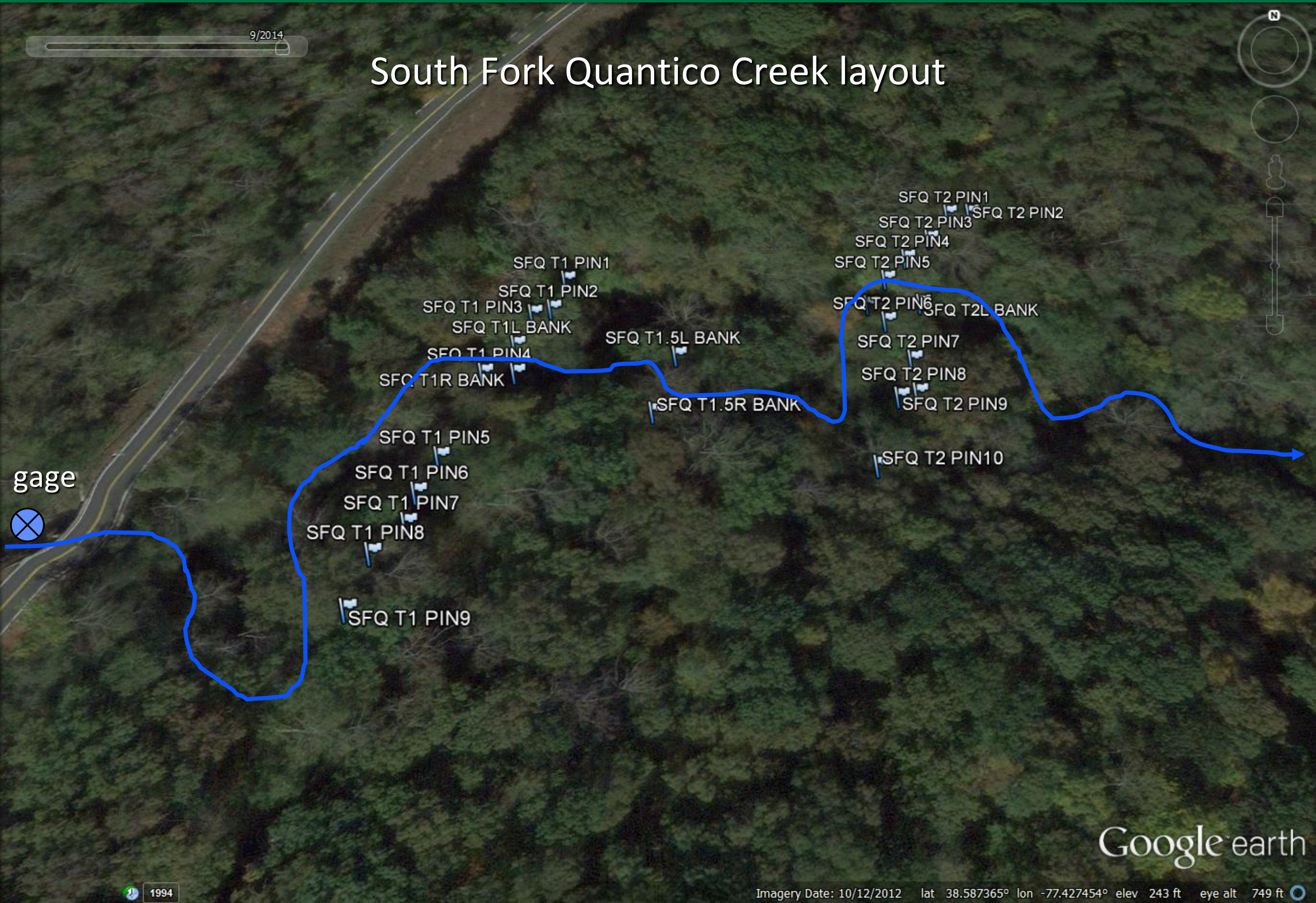
Morgan Creek, MD

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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USGS Chesapeake Floodplain Network

Goal:

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

The importance of floodplains to WQ in the Chesapeake watershed

Measurement of functions

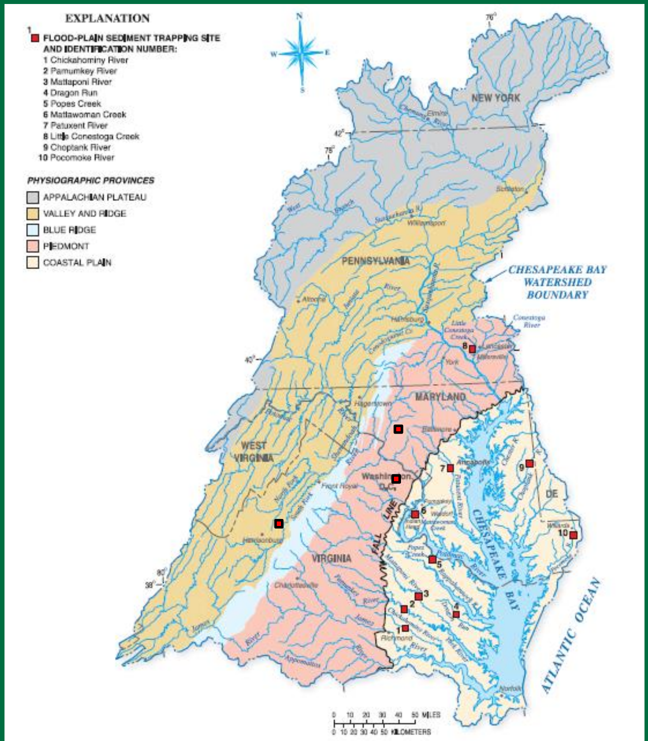

Figure 2. Location of flood-plain sediment trapping sites in the Chesapeake Bay Watershed. [Dates of measurements range from 1996 through 2006 (modified from Bachman and others, 1998).]

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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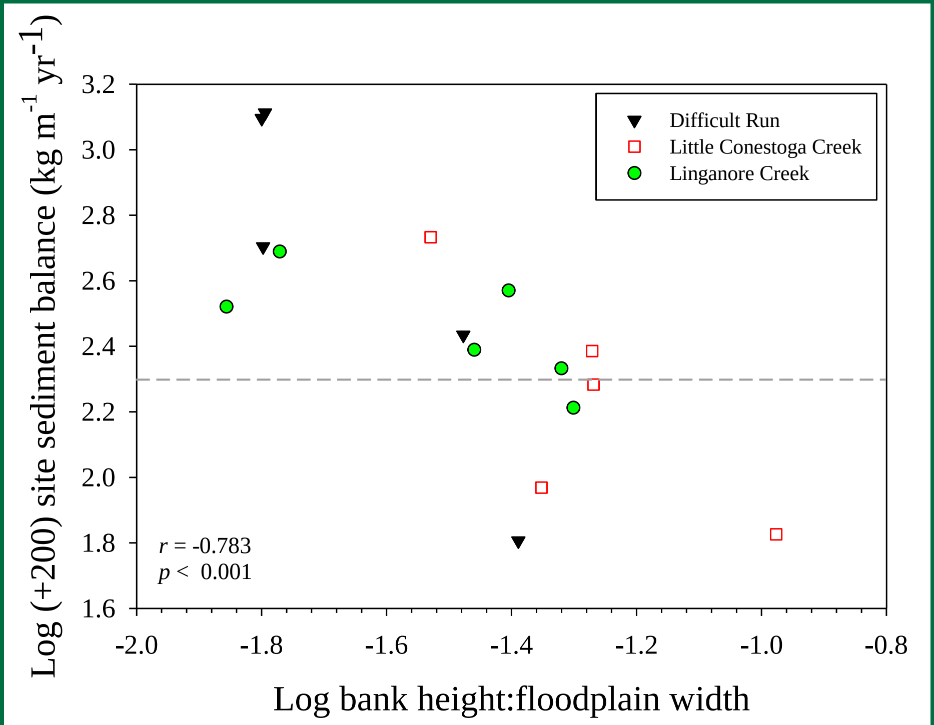
Predictability of functions



Schenk et al. 2013, *ESP&L*

Gellis et al. 2015, SIR

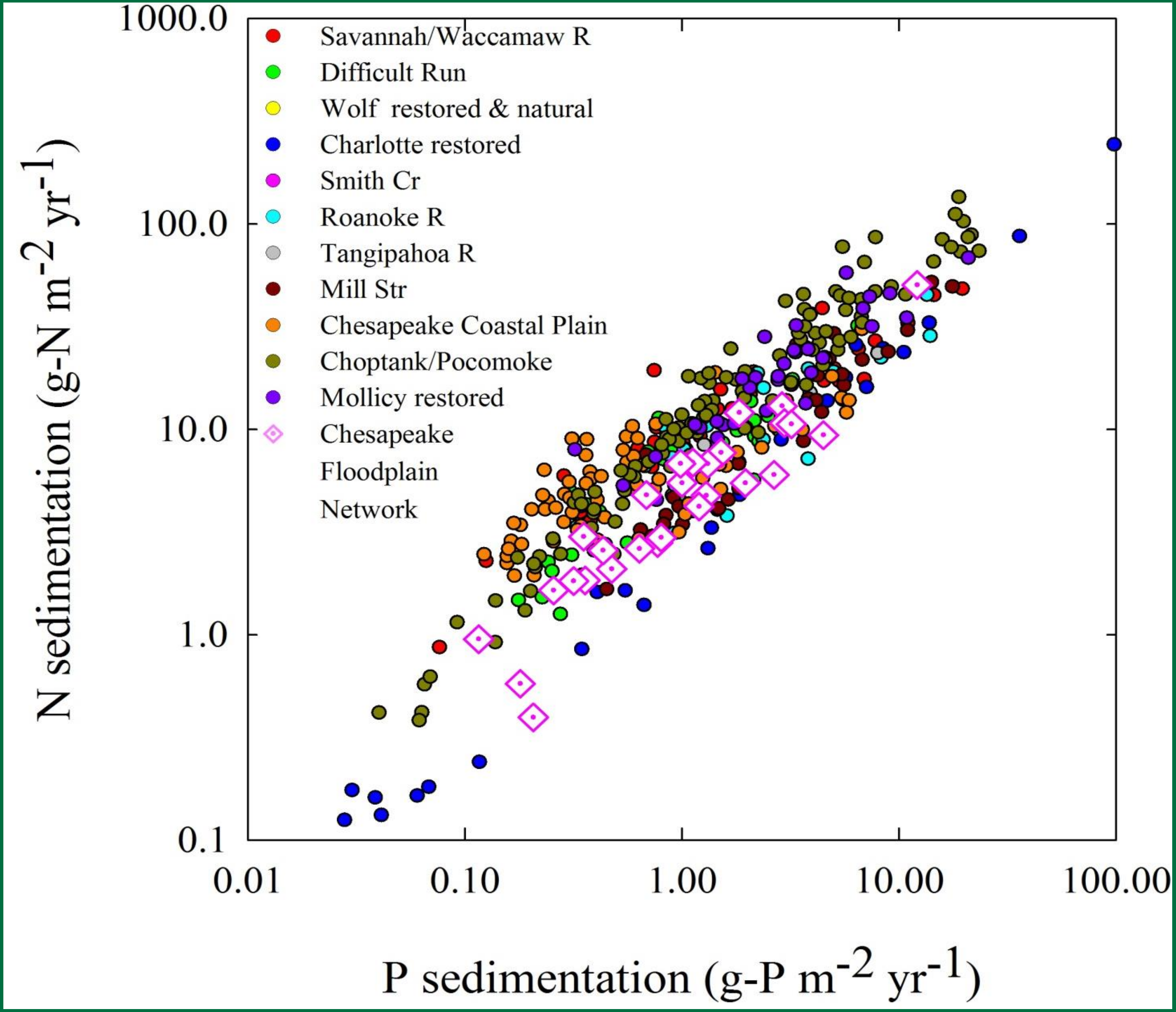
Only 3 Piedmont watersheds!

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

Easy geomorphic metrics may be predictive

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

USGS