



**Nitrogen removal in forests and riparian buffers:
The role of spatially variable hydro-ecology**

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University of Delaware**

**CBP STAC Workshop
Healthy Watersheds
March 7-8, 2012**



Questions

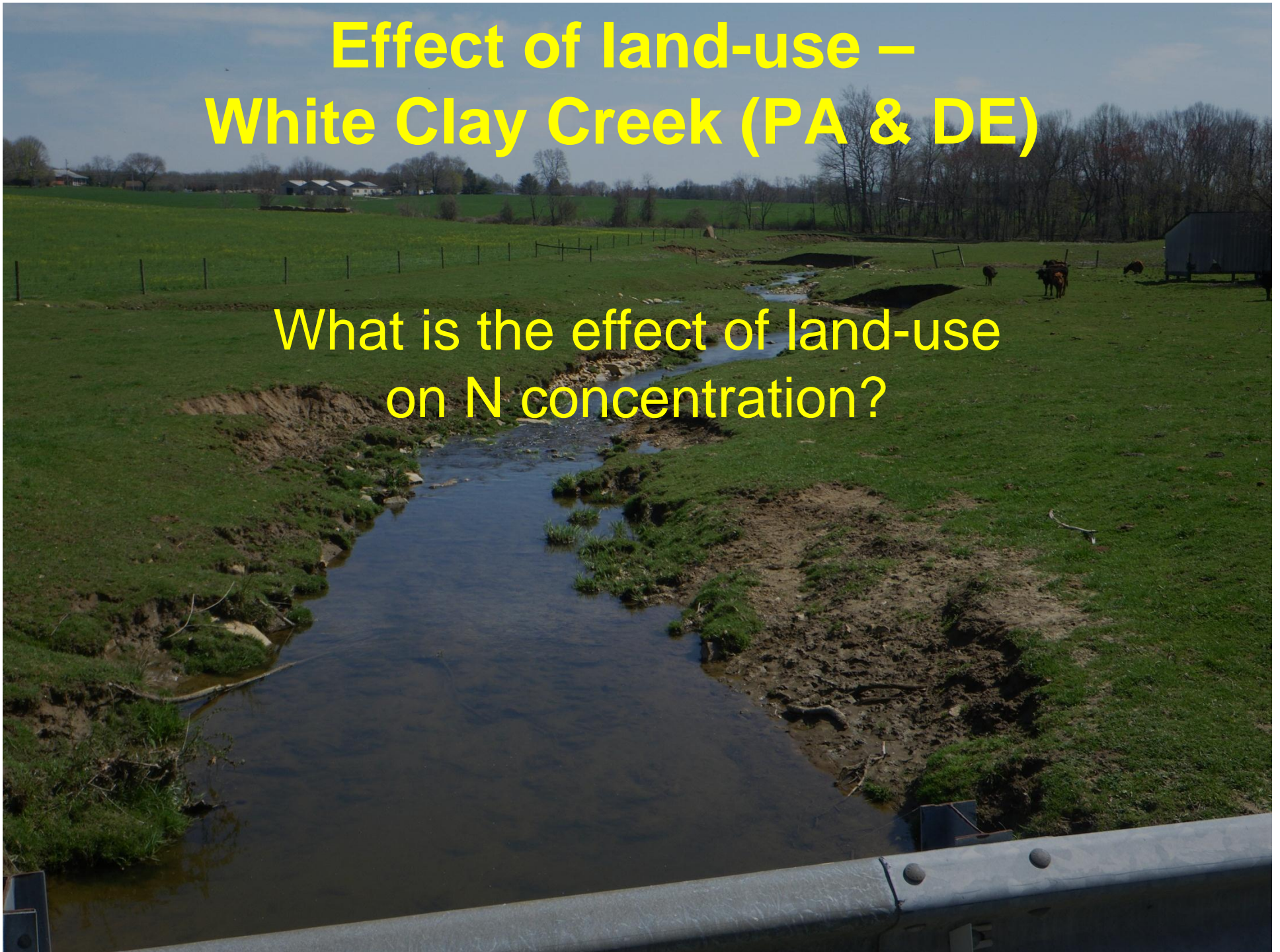
1. **What is the effect of land-use on N concentration?**
2. **How does spatial organization of land cover affect N concentration?**
3. **How can we quantify the effect of landscape features on N removal?**

Case Studies

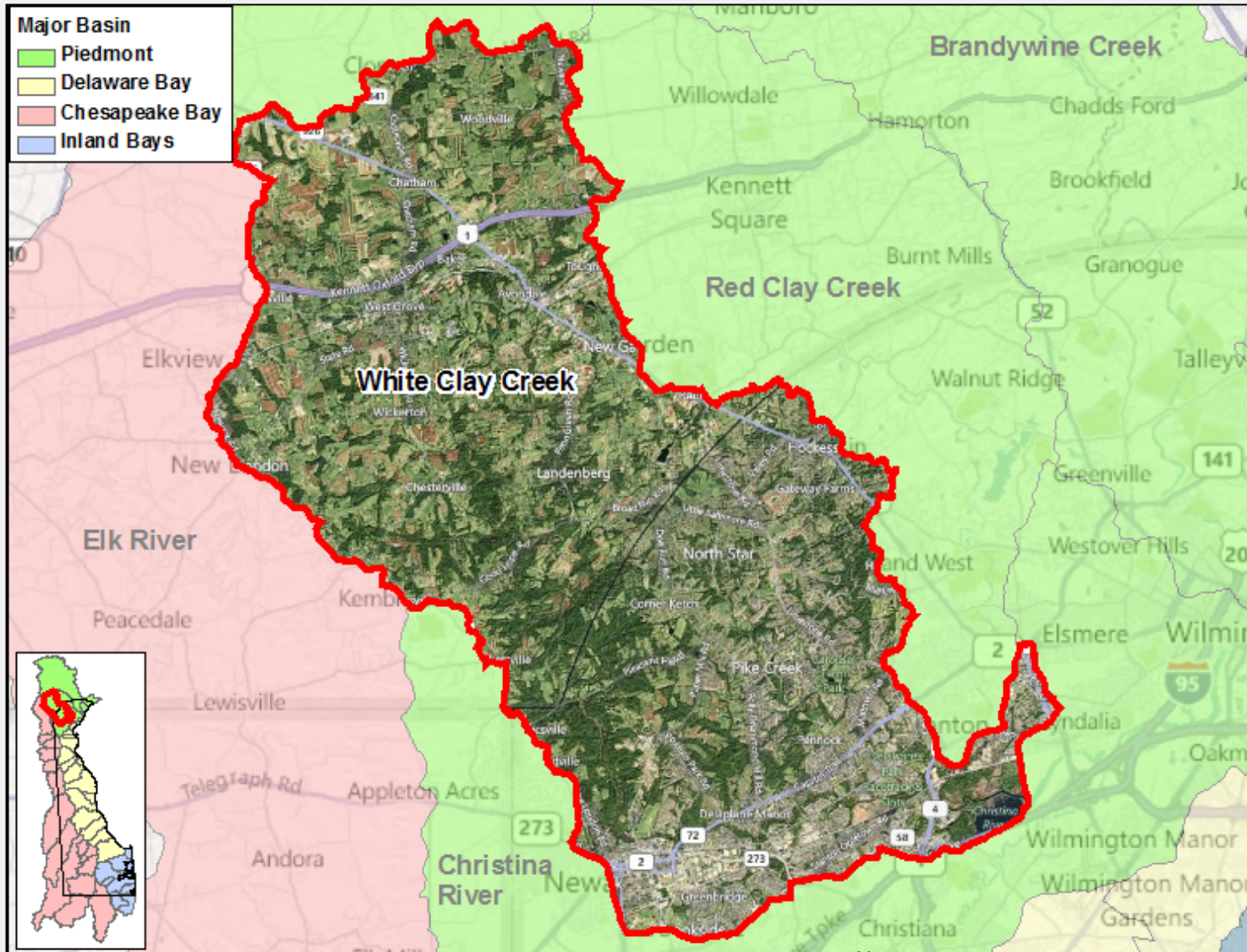
- **Effect of land-use – White Clay Creek (PA & DE)**
- **Effect of spatial organization – Opequon Creek (VA & WV)**
- **Spatial process-based modeling – Baisman Run (MD)**

Effect of land-use – White Clay Creek (PA & DE)

What is the effect of land-use
on N concentration?



White Clay Creek Watershed

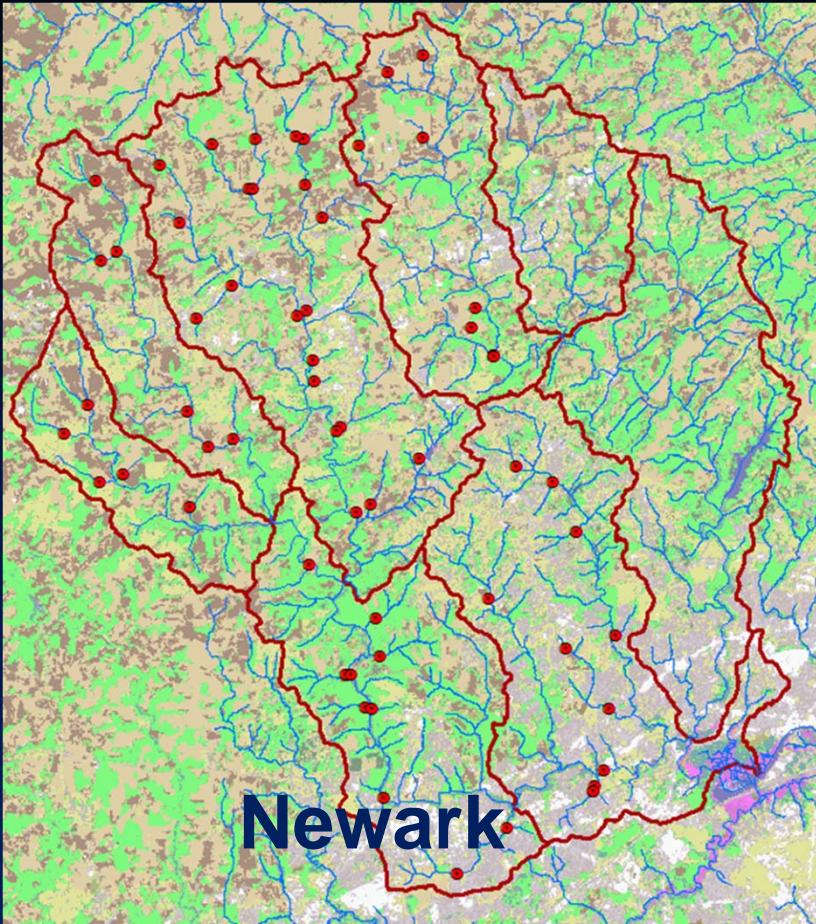


~280 km²



<http://delawarewatersheds.org/>

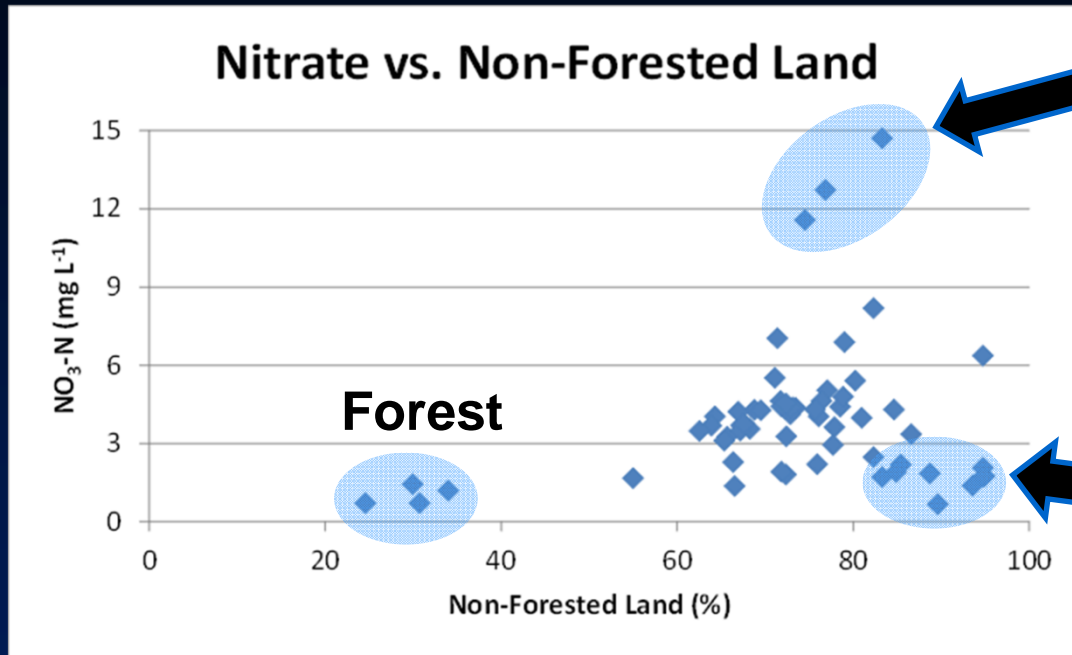
Snapshot Sampling



- ~60 stations; sampled in April 2011 during 'baseflow'.
- Range of land-use (forested, agricultural, developed, mixed).
- Mostly headwater streams.



Effect of Land-Use



- N conc. has direct relationship with non-forested land-use.
- Urbanized areas have relatively low N conc.; N reduction efforts in these areas will lead to only minimal improvements.
- 'Concentrated' sources (loading and flow) in agricultural areas are opportunities for targeted N reduction efforts.

Enhancing N Removal – Innovative Approach

Permeable reactive barriers, “denitrification walls”

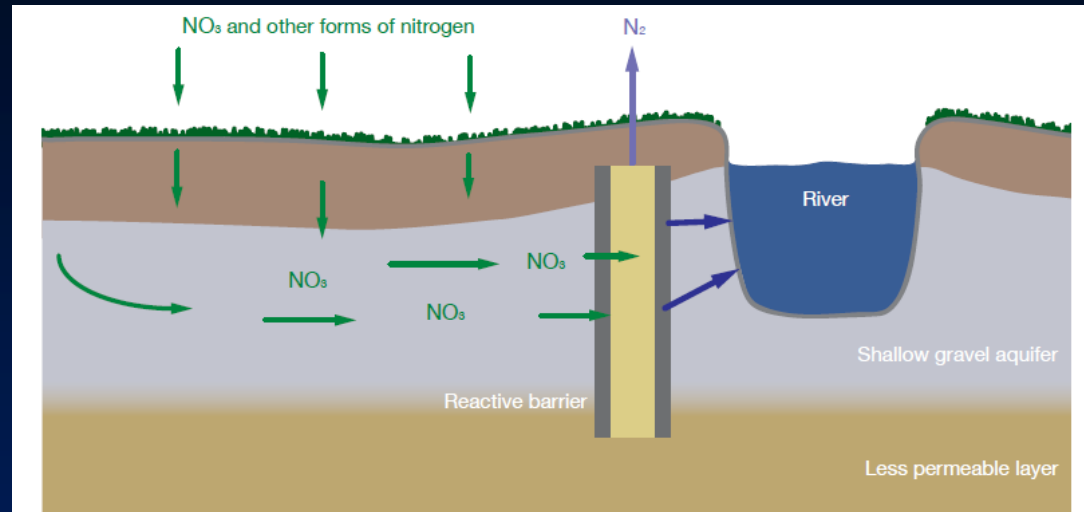


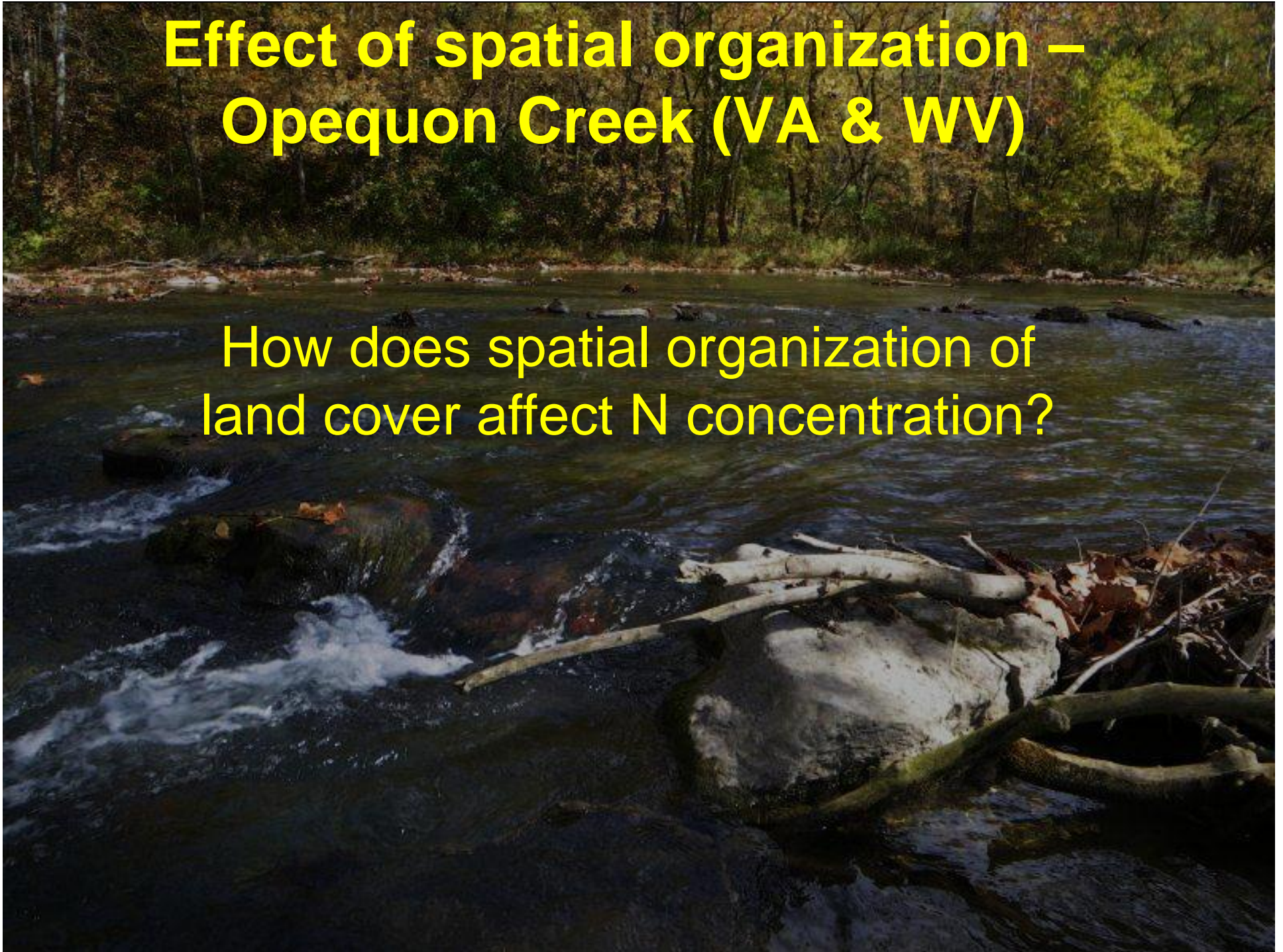
Figure 2.1: Schematic diagram of a PRB for treating nitrate-contaminated water.

(<http://www.nitrabar.eu>)

- Organic carbon substrate → immediate N reduction
- Potentially treat surface water → no long lag times associated with most BMPs → immediate lowering of stream N

Effect of spatial organization – Opequon Creek (VA & WV)

How does spatial organization of
land cover affect N concentration?



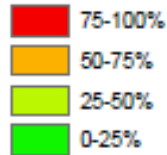
Urban Sources of Total Nitrogen

Quartile Ranking within the Chesapeake Bay Watershed

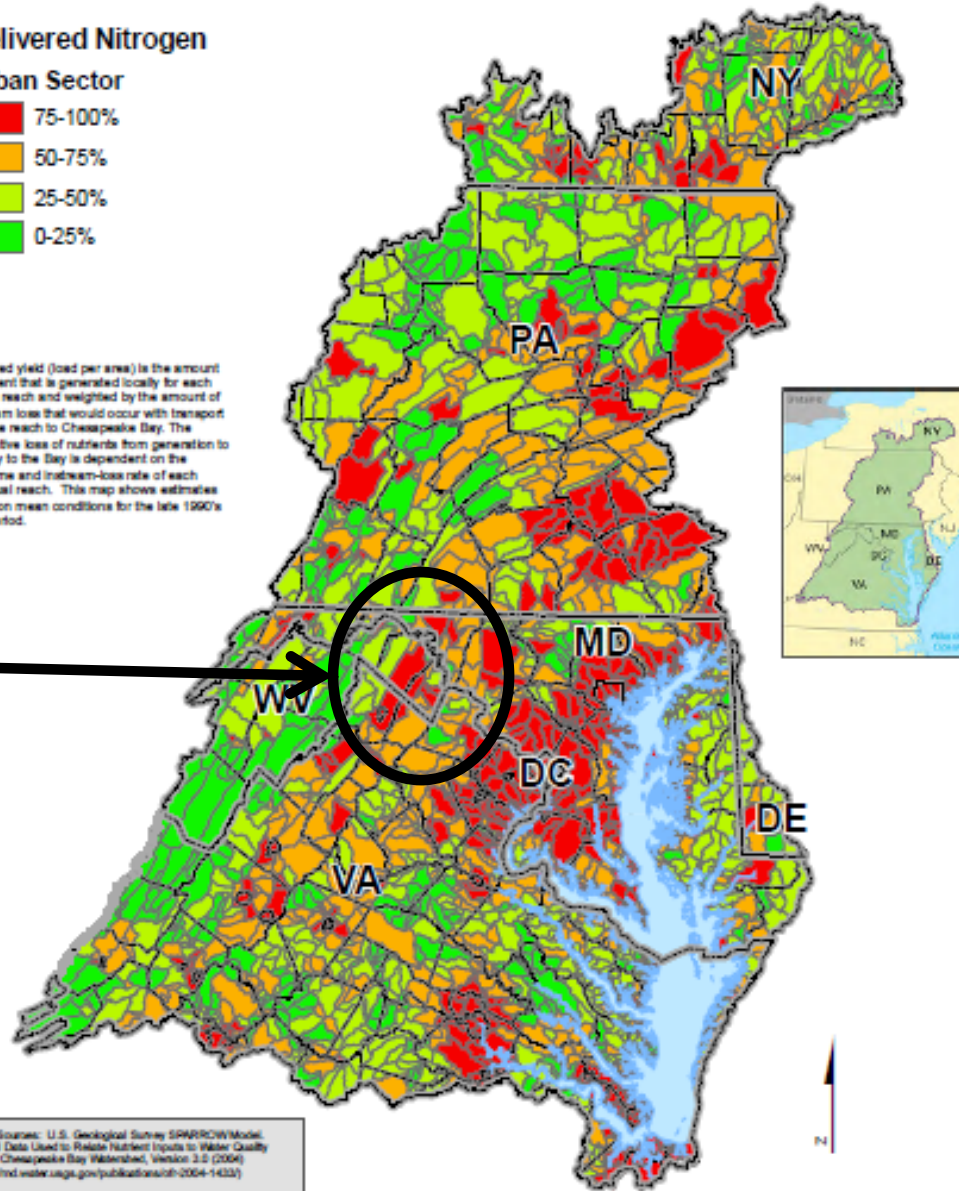


Delivered Nitrogen

Urban Sector



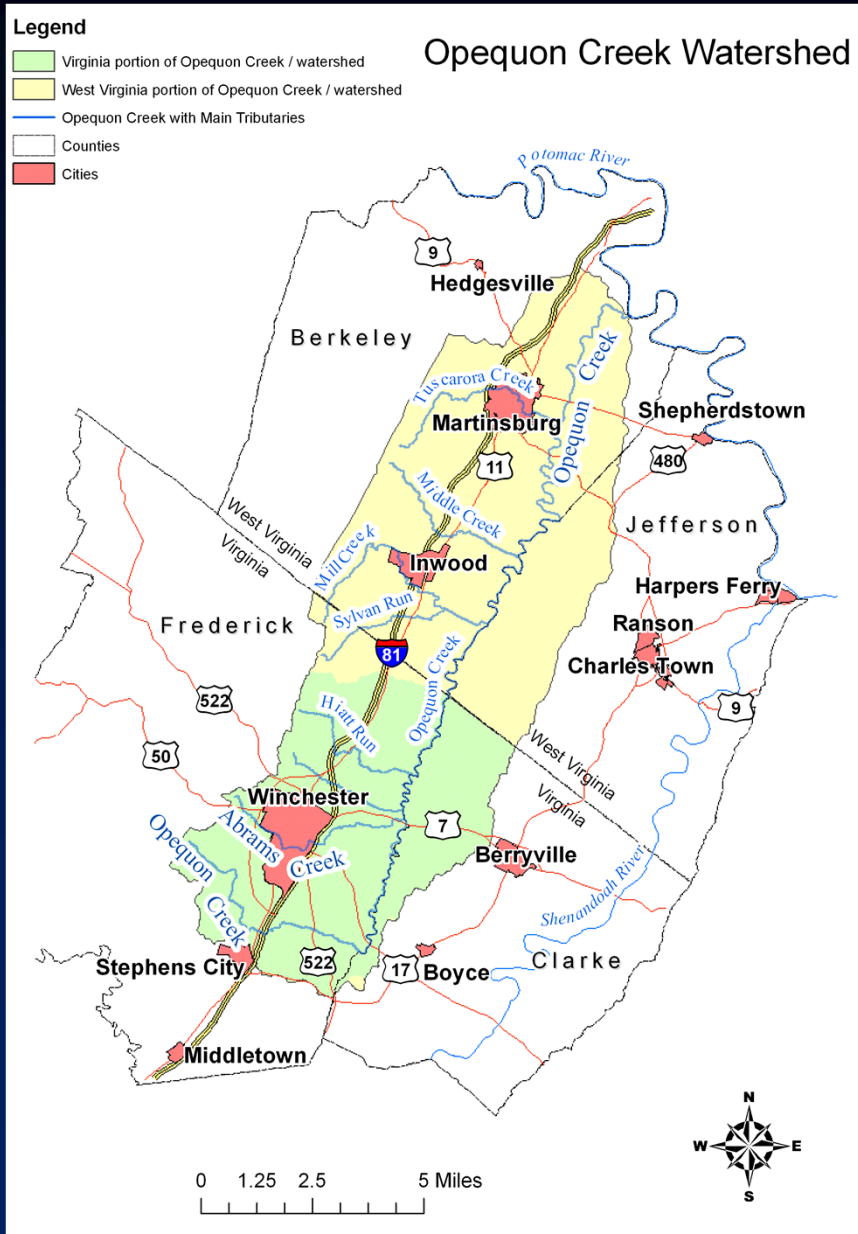
Delivered yield (load per area) is the amount of nutrient that is generated locally for each stream reach and weighted by the amount of in-stream loss that would occur with transport from the reach to Chesapeake Bay. The cumulative loss of nutrients from generation to delivery to the Bay is dependent on the traveltime and in-stream-loss rate of each individual reach. This map shows estimates based on mean conditions for the late 1990's time period.



Opequon
Creek
watershed

Data Sources: U.S. Geological Survey SPARROW Model, Digital Data Used to Rescale Nutrient Inputs to Water Quality in the Chesapeake Bay Watershed, Version 3.0 (2004) (<http://nd.water.usgs.gov/publications/wh-2004-1433/>)
For more information, visit www.chesapeakebay.net
Disclaimer: www.chesapeakebay.net/structure/wh-2004-1433/

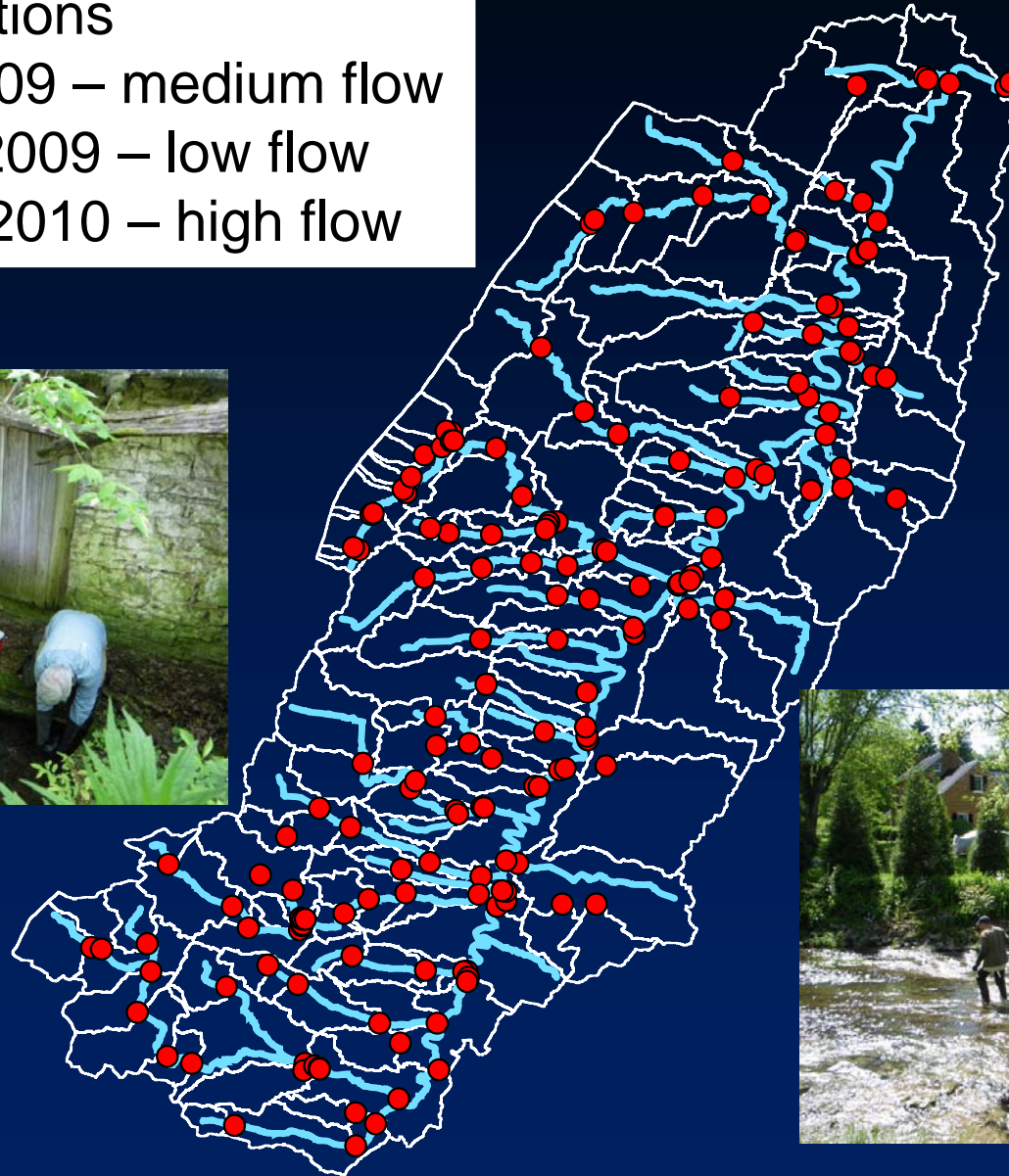
Opequon Creek Watershed



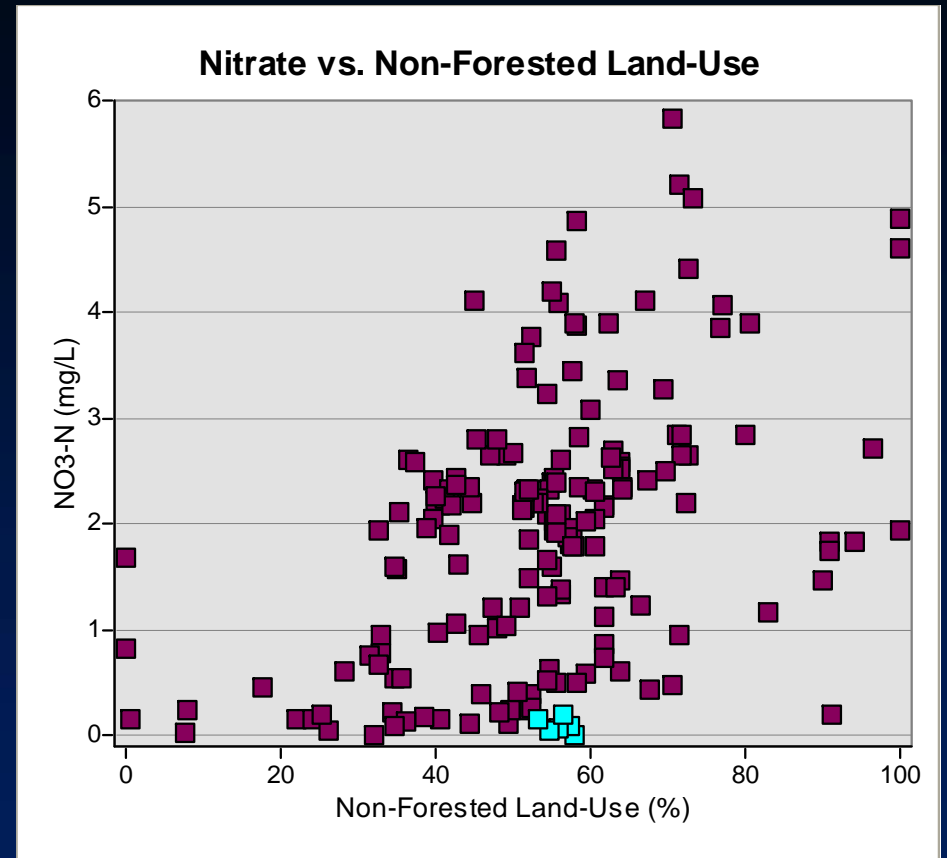
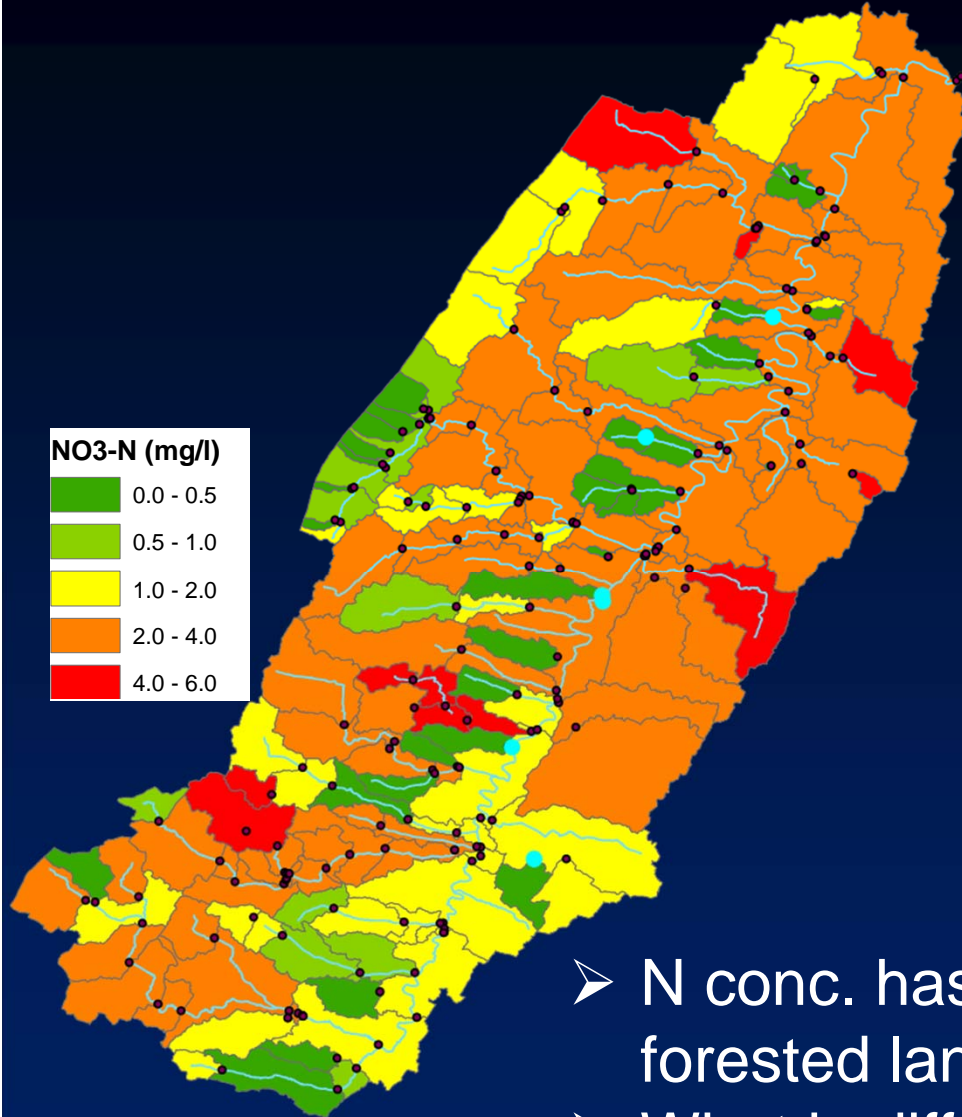
- 890 km²
- Mixed land use, with rapid conversion of agricultural to residential.
- Impairments of nutrients, sediment and bacteria.
- Source of nutrients:
 - Point sources
 - Agricultural NPS
 - Urban NPS

Snapshot Sampling

- 130-180 stations
- Jun 1-10 2009 – medium flow
- Oct 22-23, 2009 – low flow
- Mar 24-25, 2010 – high flow

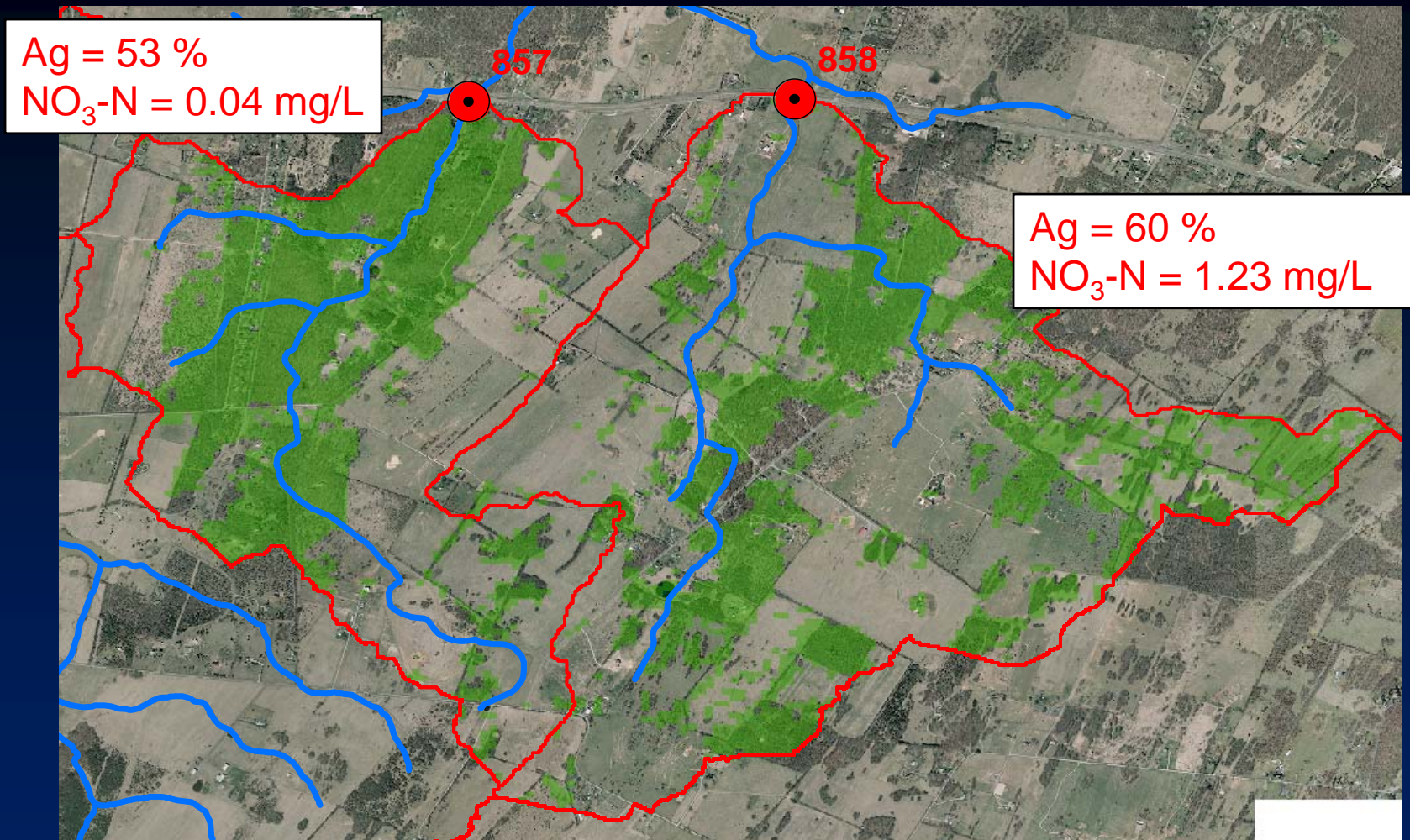


Land-Use Effects



- N conc. has direct relationship with non-forested land-use.
- What is different about watersheds that don't follow the expected pattern?

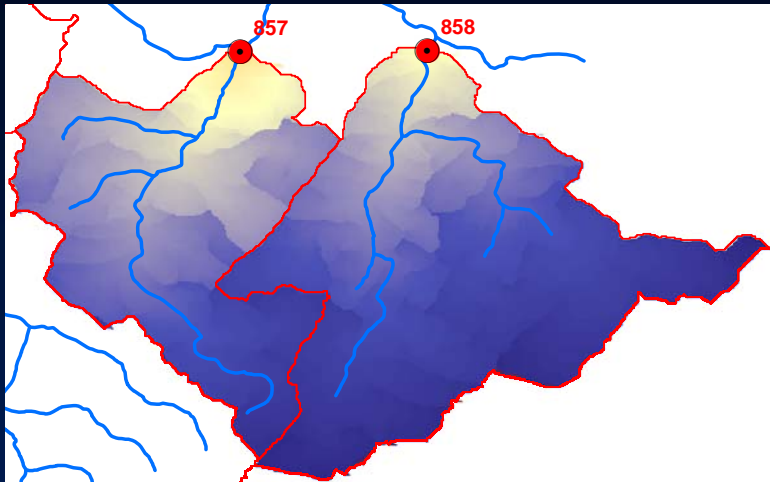
Land-Use Effects



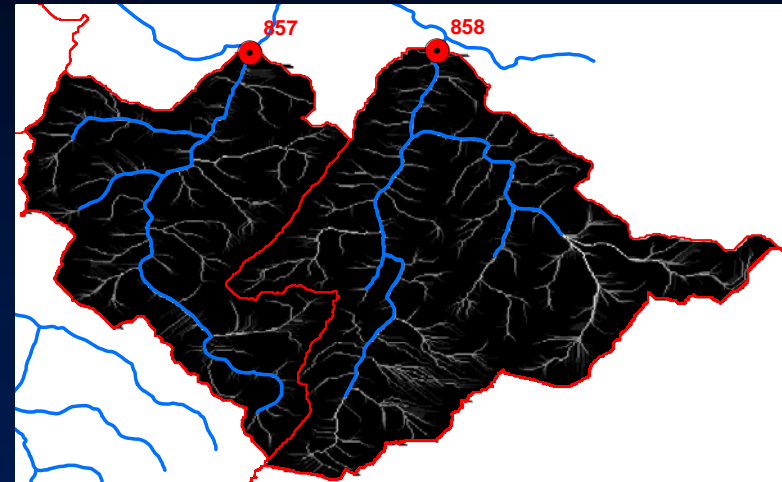
- Similar fractional land-use, but distinct N conc.
- Lumped categorization might not capture relevant N removal processes.

Spatial Metrics of Hydrologic Connectivity

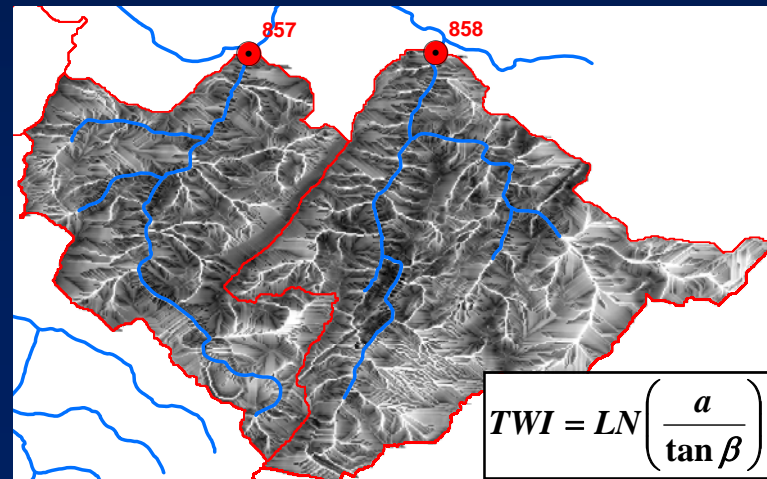
Flow Distance



Flow Accumulation



Topographic Wetness Index



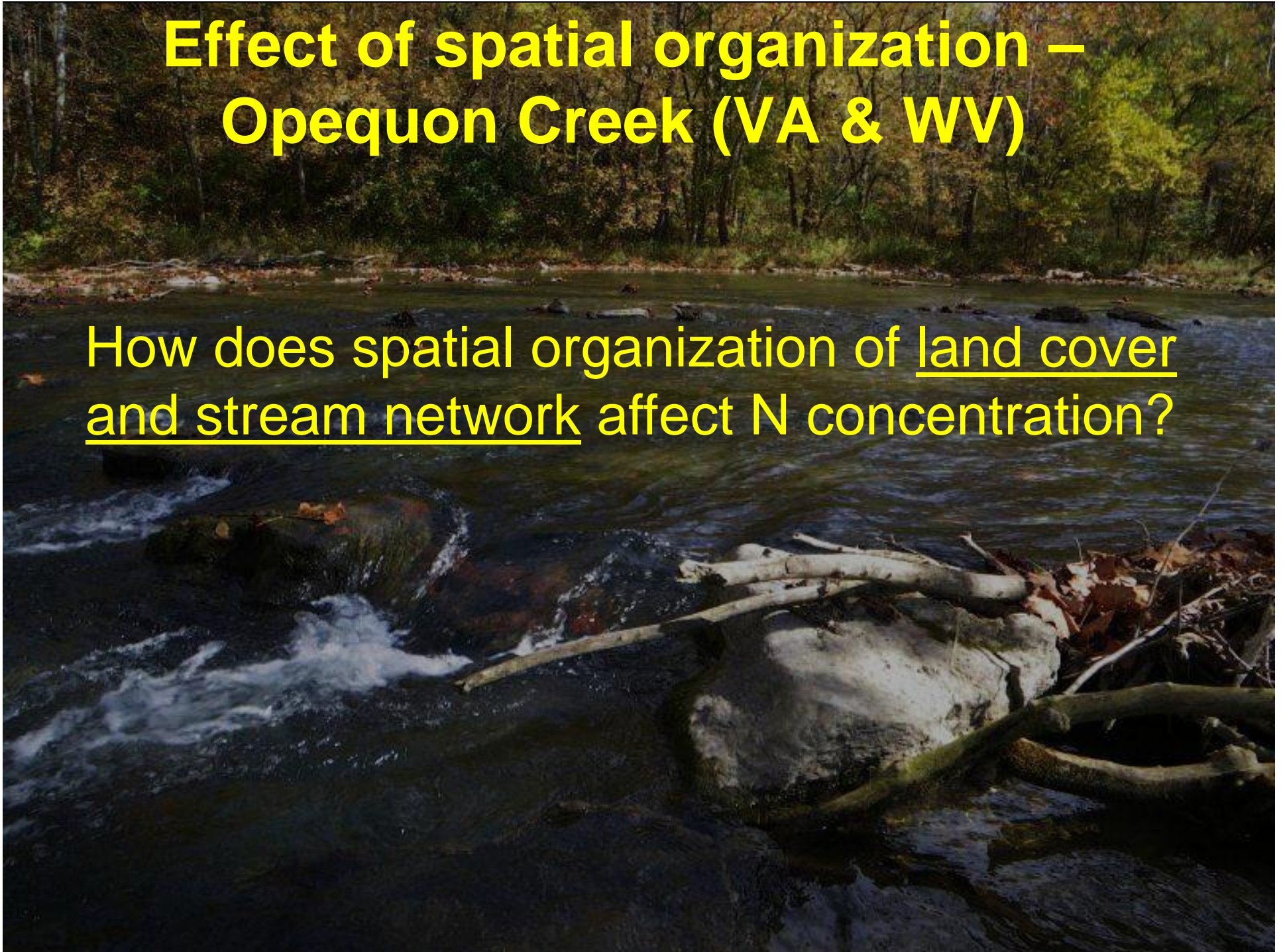
Spatial Weighting to Predict 'Effective' Land-Use

Station	NO ₃ -N (mg/L)	Non-Forested Land-Use (%)			
		Lumped	Weighted by Flow Accumulation	Weighted by Wetness Index	Weighted by Distance
857	0.04	57.5	23.8	58.0	50.2
858	1.23	66.0	74.8	65.5	69.7

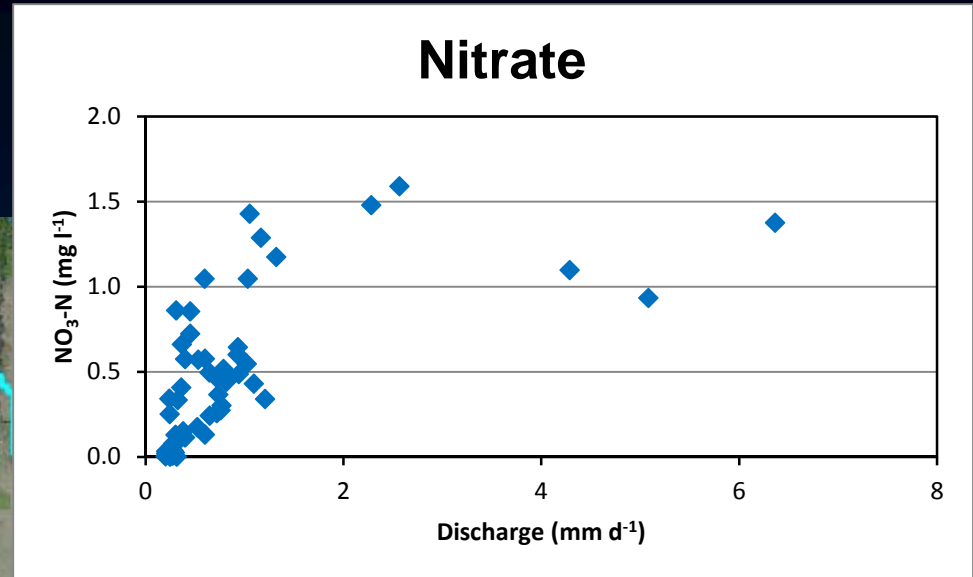
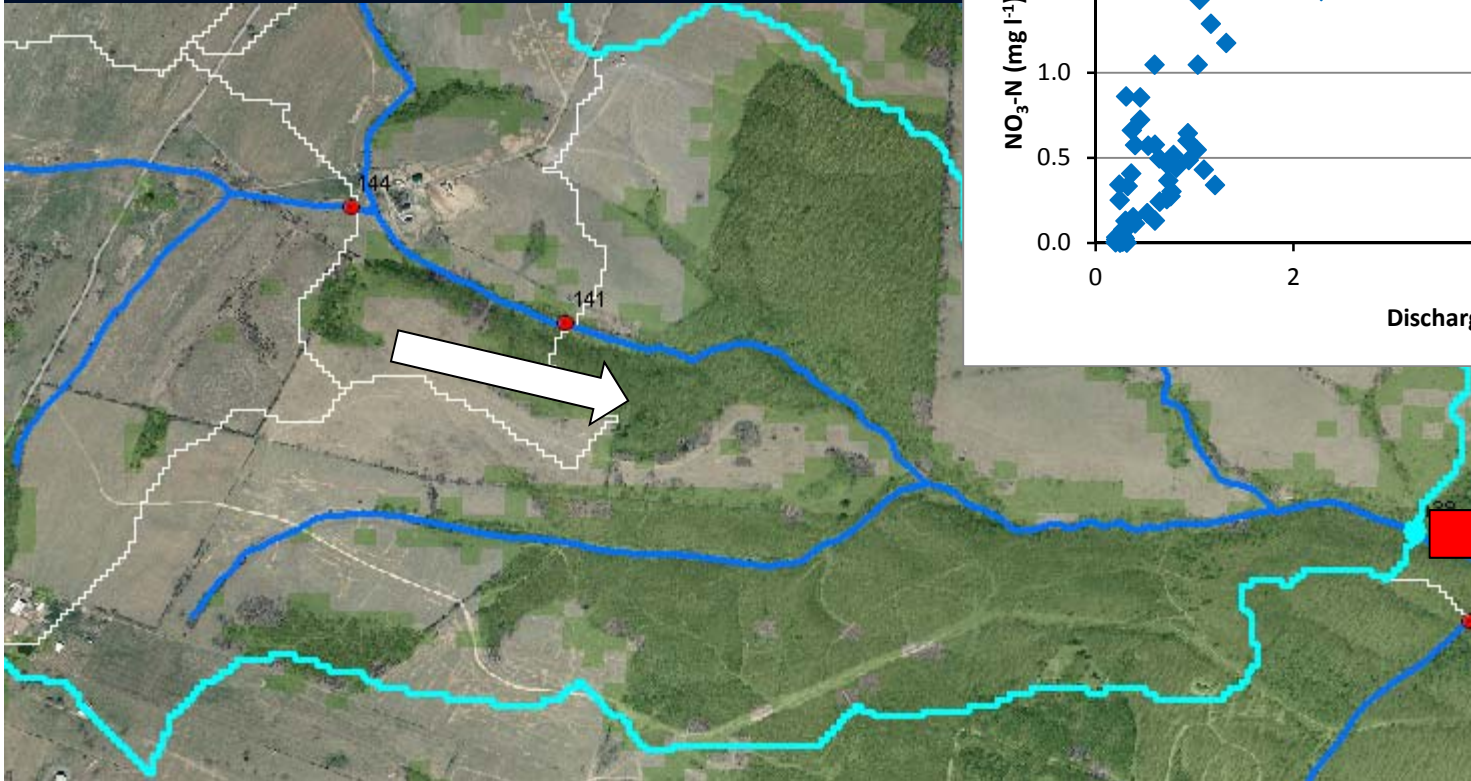
- Spatial weighting using flow accumulation improves predictive ability of land-use effects on NO₃ concentration.
- Accounting for spatial factors is critical for watershed modeling and mitigation, conservation and restoration efforts.
- Models currently used for decision-making are based on lumped or semi-distributed approaches. **Spatial factors could be incorporated by using 'effective' land-use instead of true proportional land-use.**

Effect of spatial organization – Opequon Creek (VA & WV)

How does spatial organization of land cover
and stream network affect N concentration?



Forested Riparian Corridor



- Removal processes are evident through direct relationship.
- Suggests role of riparian forests and C-N linkages in in-stream N removal.

Forested Riparian Corridor

- Riparian forests provide OM to streams and sustain important ecological functions.
- However, the relative importance of in-stream processes for N removal is debated.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, G04016, doi:10.1029/2009JG001017, 2009

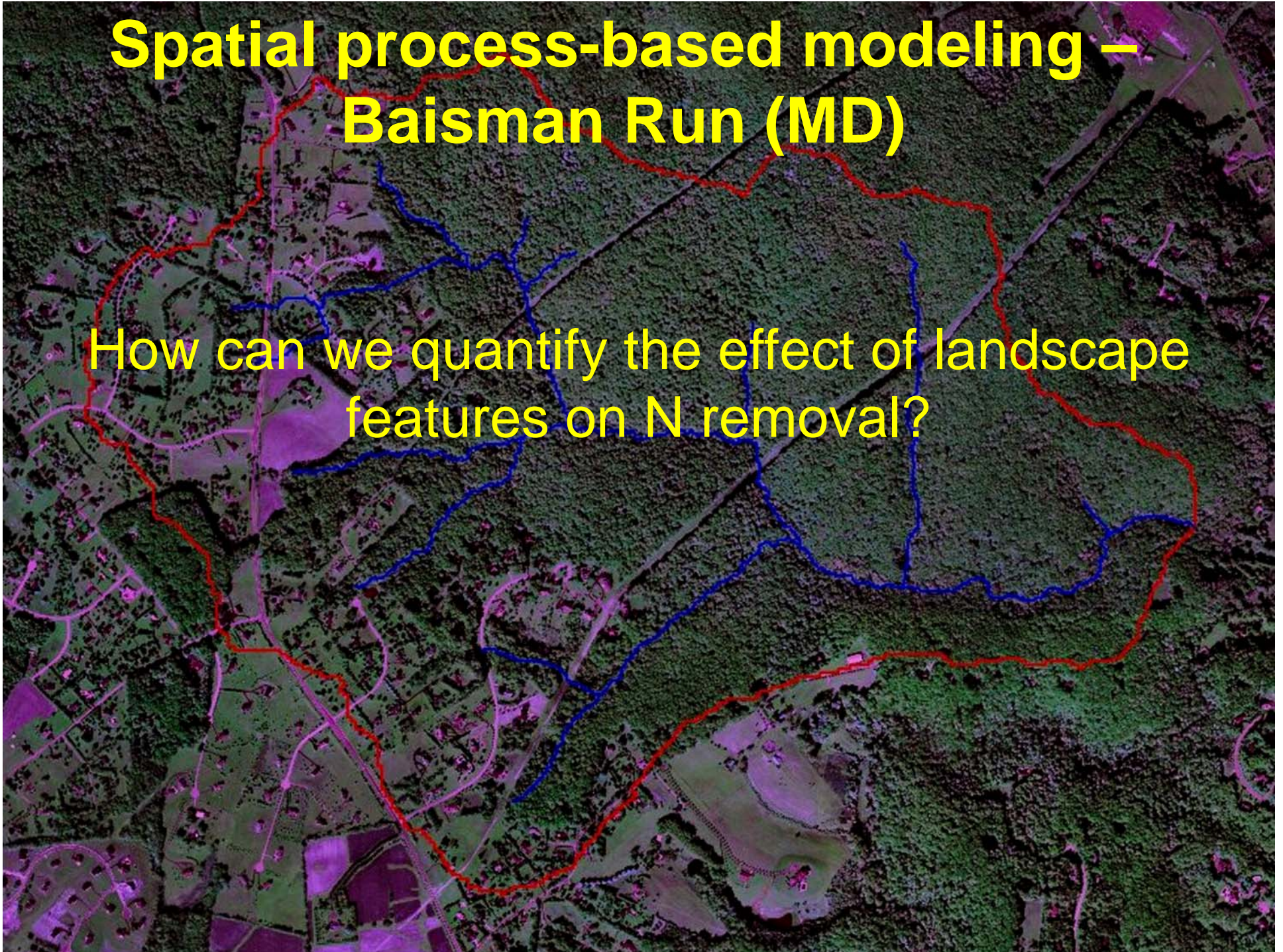


Hydro-ecological linkages in urbanizing watersheds: An empirical assessment of in-stream nitrate loss and evidence of saturation kinetics

Luc Claessens,^{1,2,3} Christina L. Tague,⁴ Lawrence E. Band,⁵ Peter M. Groffman,⁶
and Stephen T. Kenworthy⁷

Spatial process-based modeling – Baisman Run (MD)

How can we quantify the effect of landscape features on N removal?



Possible Questions

- spatial - where should we have buffers?
- design - what should be the configuration (e.g., width)?
- process - how effective would the buffer be?
- temporal - how long would it take to become effective?

We need process-based models (and empirical data!) to gain an improved understanding of the spatio-temporal linkages between hydrology and ecosystems process.

Models need to be parsimonious (simple) and should not suffer from equifinality (right result for wrong reason).

Spatial process-based modeling of N removal

Regional Hydro-Ecological Simulation System

RHESSYS
THE REGIONAL HYDRO-ECOLOGIC SIMULATION SYSTEM

HOME ABOUT RHESSYS INPUT DATA RHESSYS SET-UP RUNNING RHESSYS

WHAT'S NEW

[RHESSys Downloads Page](#)

[RHESSys User Interface at Colorado State](#)

RHESSys is a GIS-based, hydro-ecological modelling framework designed to simulate carbon, water, and nutrient fluxes. By combining a set of physically-based process models and a methodology for partitioning and parameterizing the landscape, RHESSys is capable of modelling the spatial distribution and spatio-temporal interactions between different processes at the watershed scale.

Within Hillslope Processes

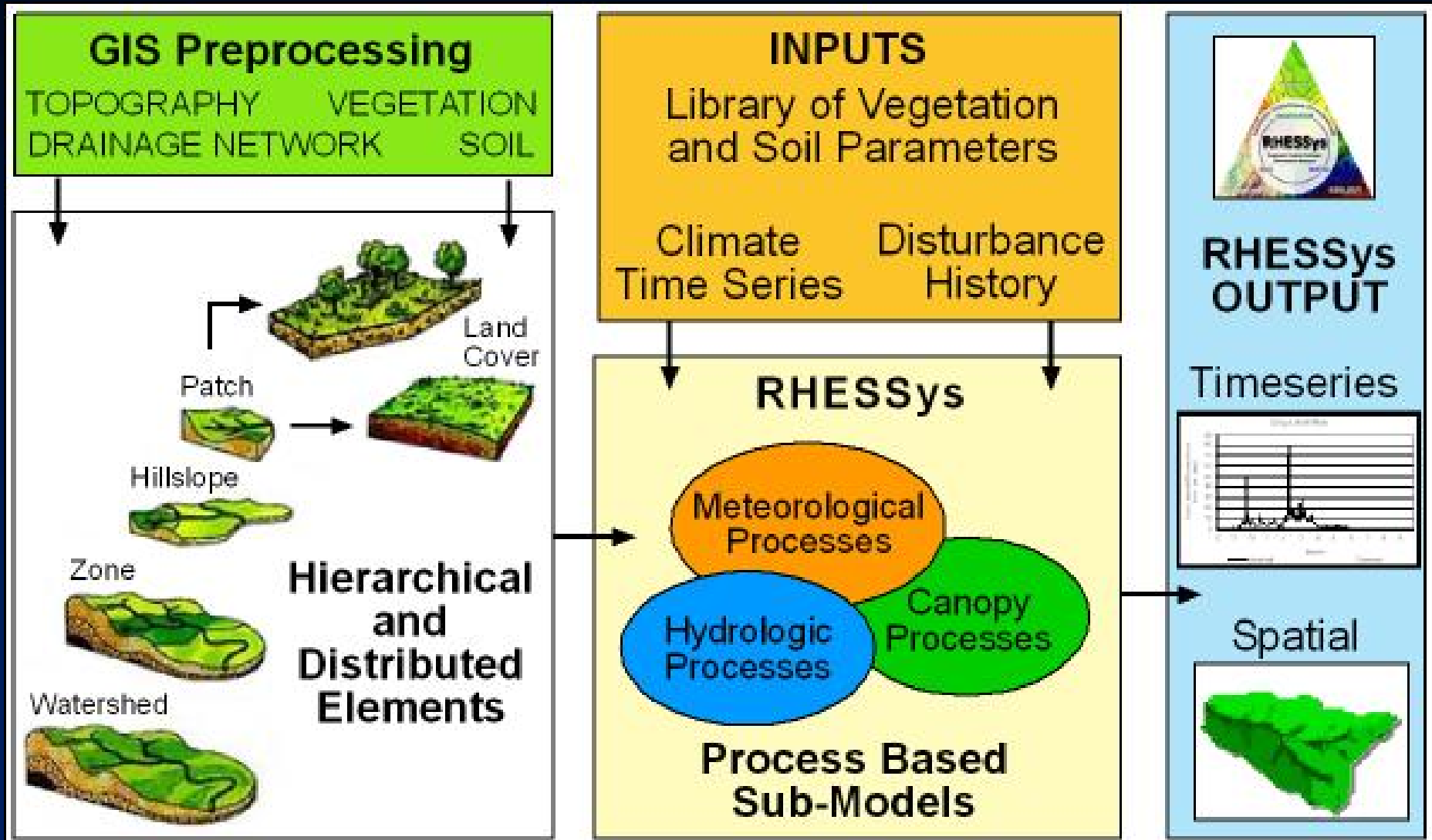
CLIMATE
VEGETATION
SOIL
WATER
TOPOGRAPHY
GEOLOGY

RHESSys
Regional Hydro-Ecologic Simulation System

Contact Us | Site Map | 2004

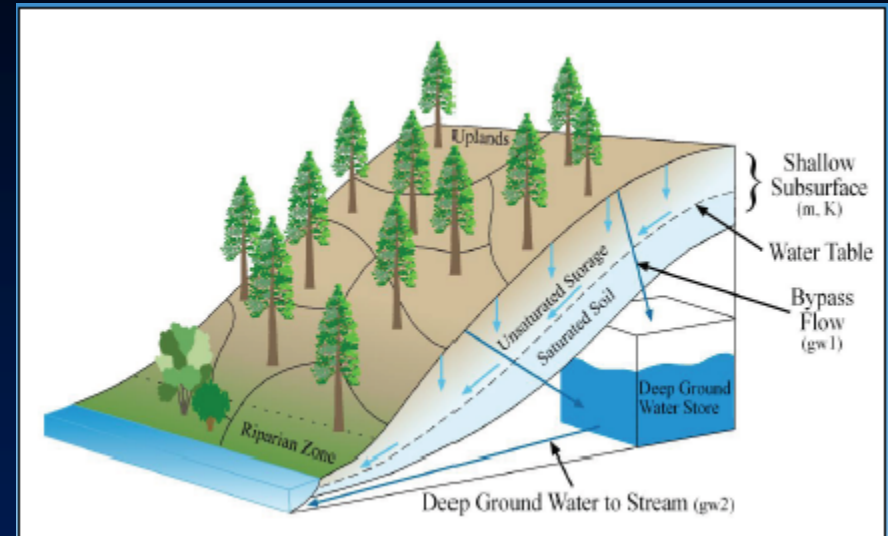
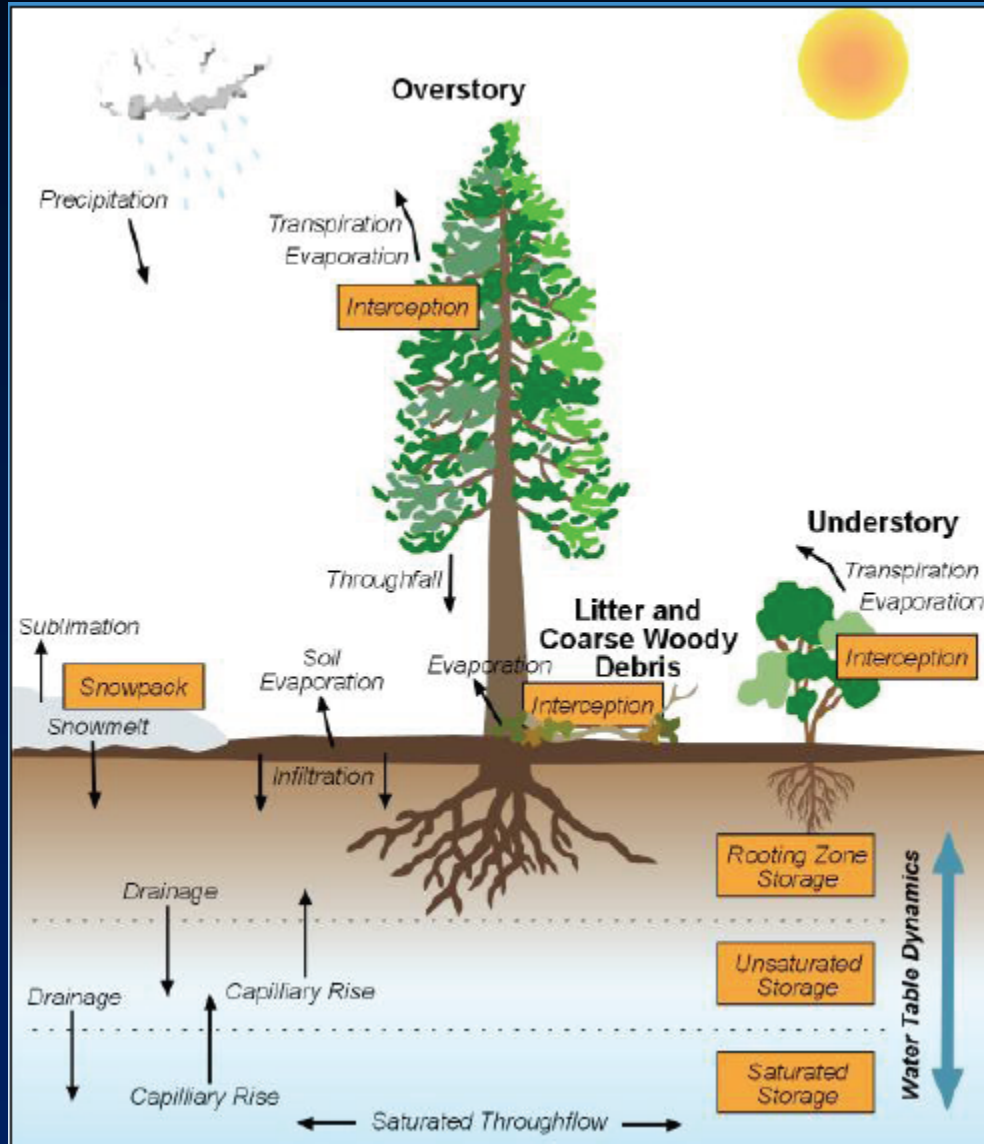
<http://fiesta.bren.ucsb.edu/~rhessys/>
Tague and Band, 2004

Computational structure of RHESSys



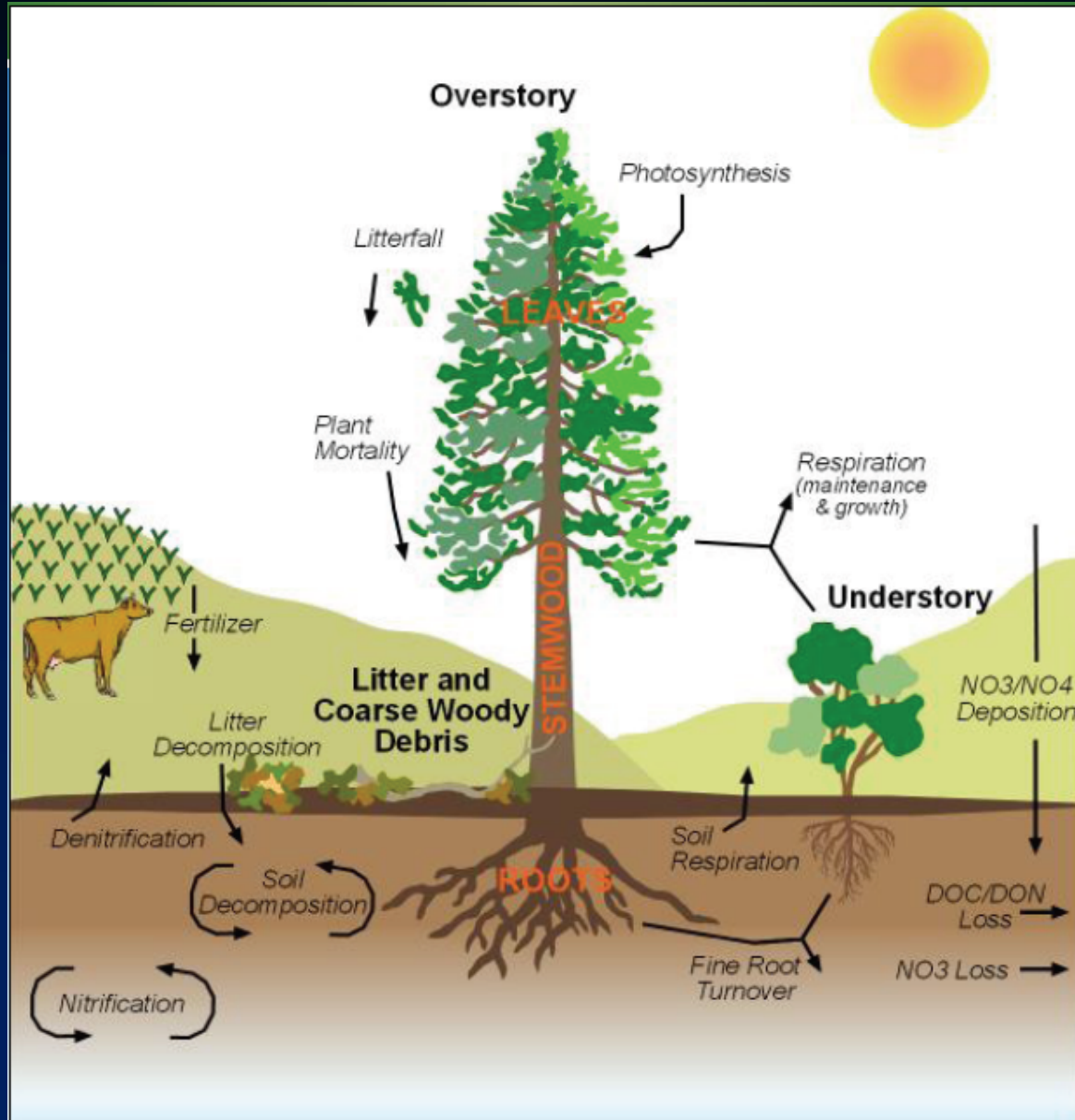
(source: C. Tague)

Vertical and lateral drainage in RHESSys



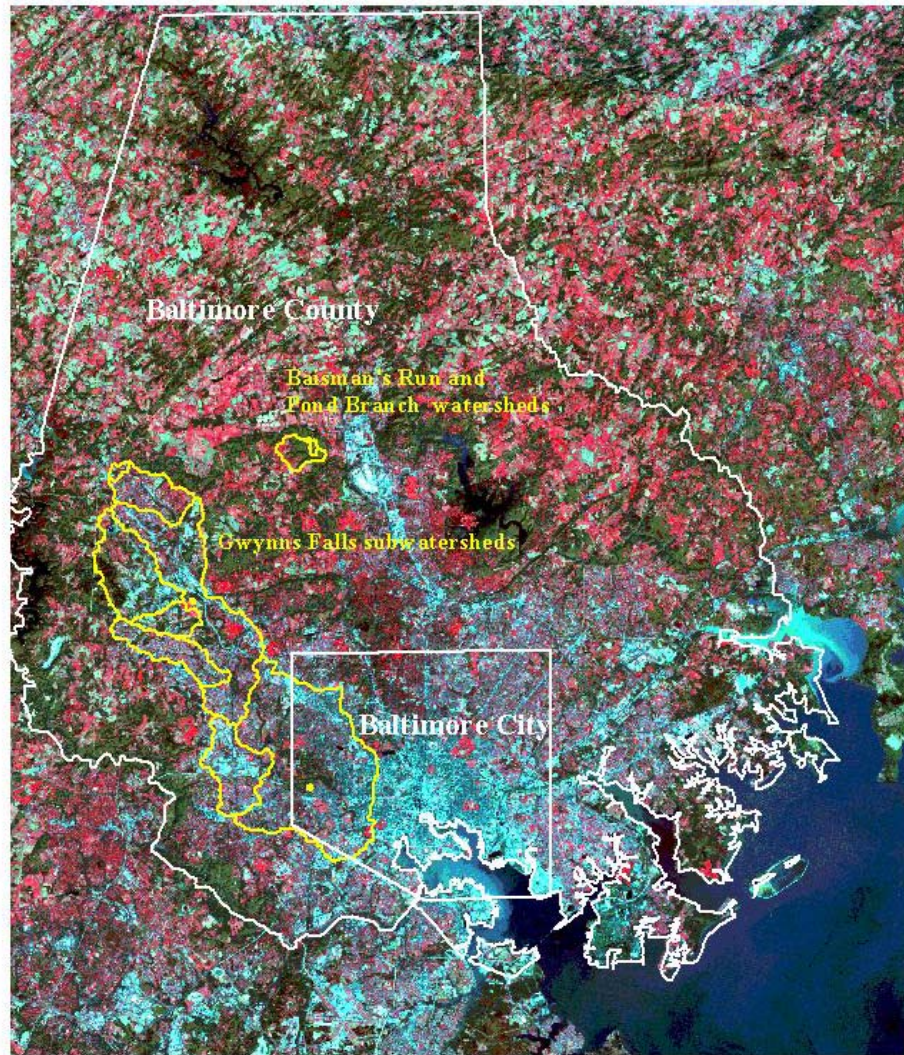
(source: Christina Taguete)

Carbon and nitrogen cycling in RHESSys




(source: Christina Tague)

Baltimore Ecosystem Study LTER

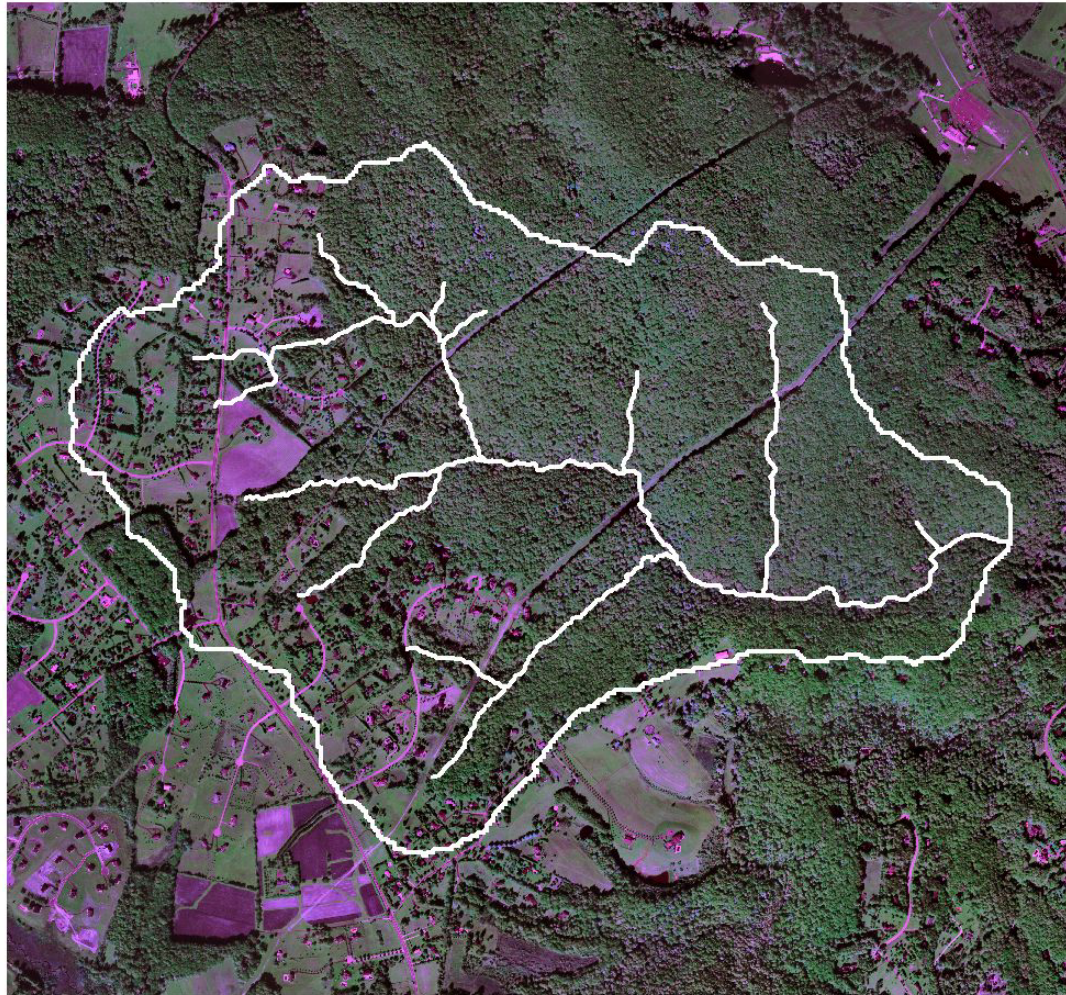


10 0 10 20 Kilometers



(Source: Larry Band)

Baisman Run Watershed



0 500 1000 Meters



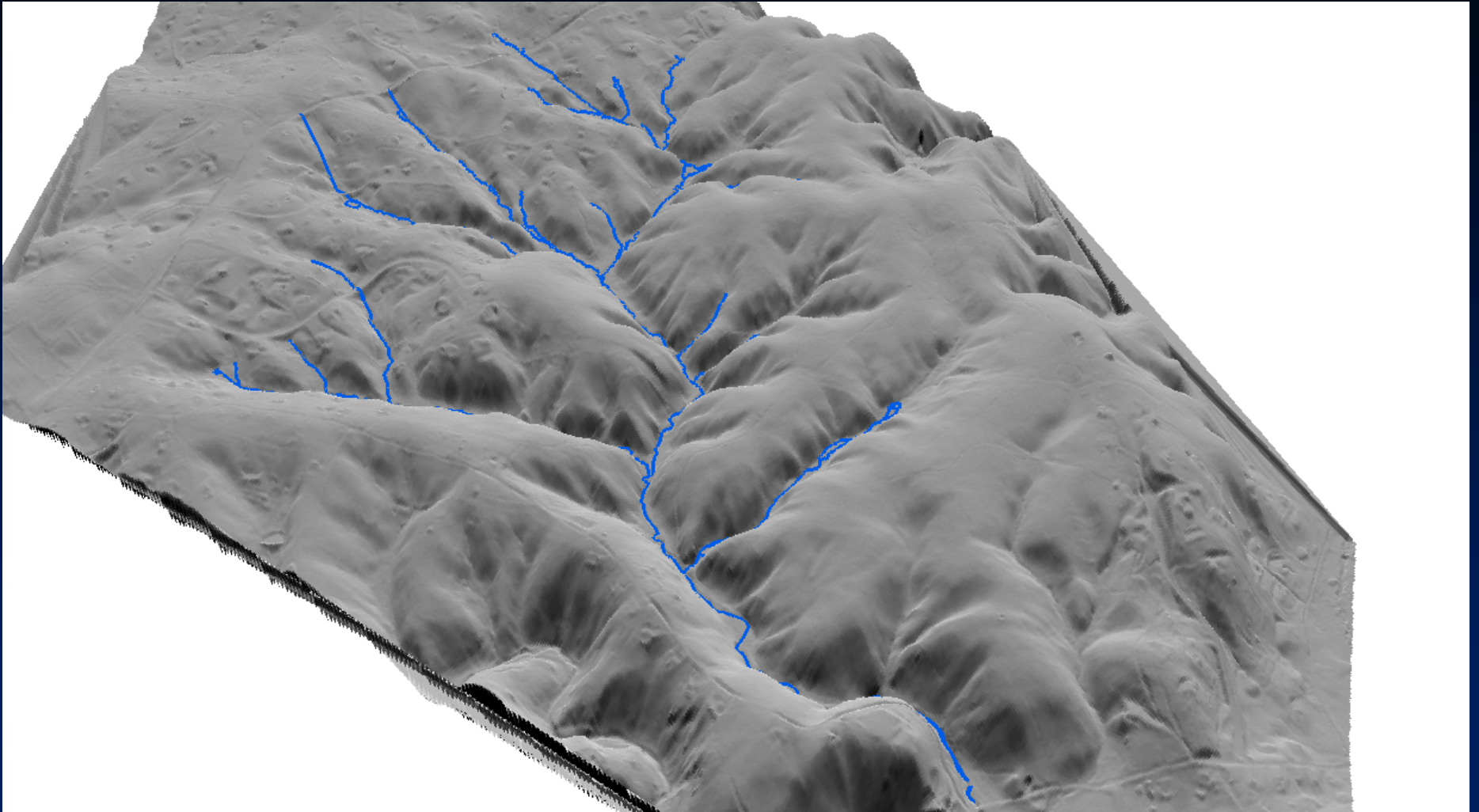
(false color image using EMERGE digital aerial imagery; RGB = 3, 1, 2)

- Monitored as part of Baltimore Ecosystem Study LTER.
- Low-density residential in head waters, all on septic; forest in lower part.
- Longitudinal step change in nitrate loading is particularly suited for studying in-stream processing.

N fluxes ($\text{g N ha}^{-1} \text{d}^{-1}$)

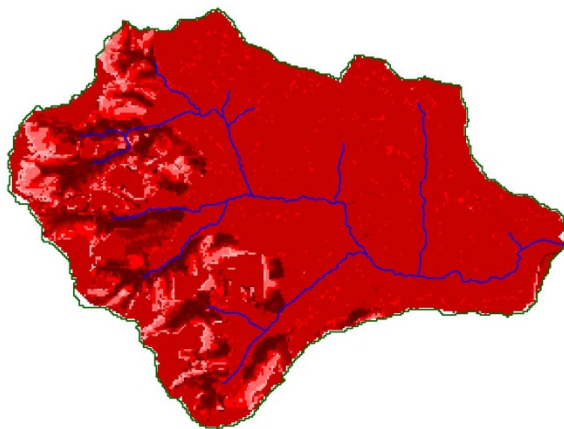
- Input = 64
- Export = 12
- Terrestrial loss = 50
- In-stream loss = 1.4

(Claessens et al., 2009 – JGR)

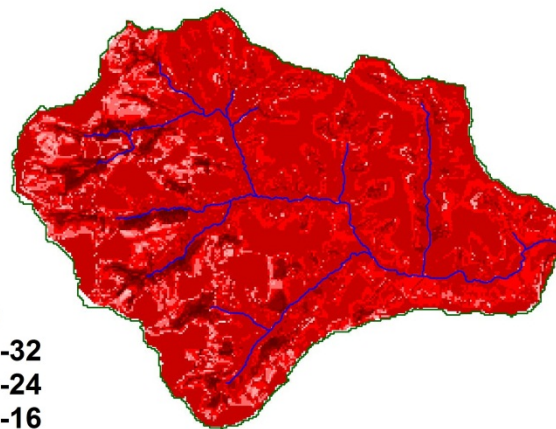


Seasonal Net Nitrate Flux (2001)

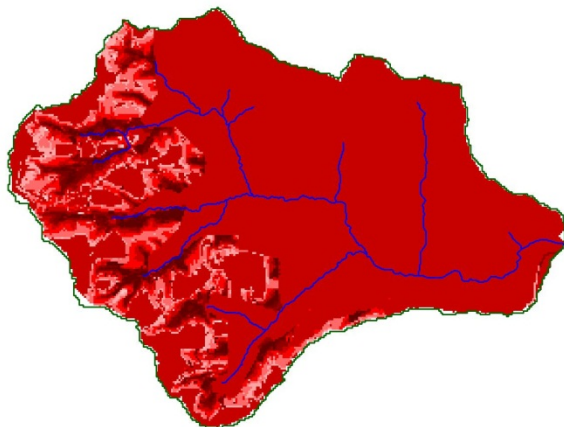
Spring



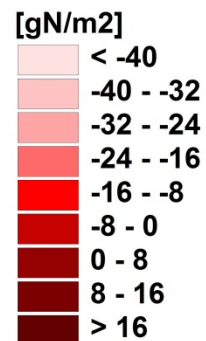
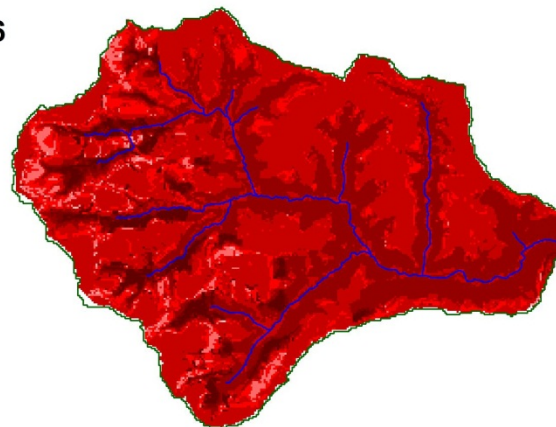
Summer



Fall

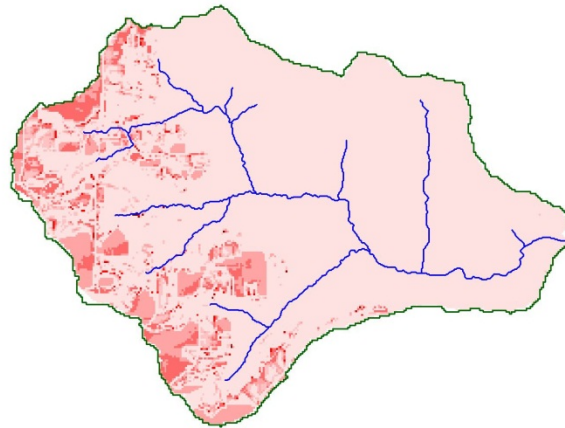


Winter

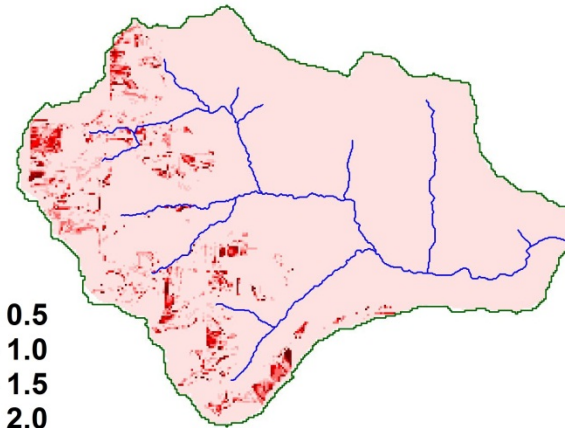


Seasonal Denitrification (2001)

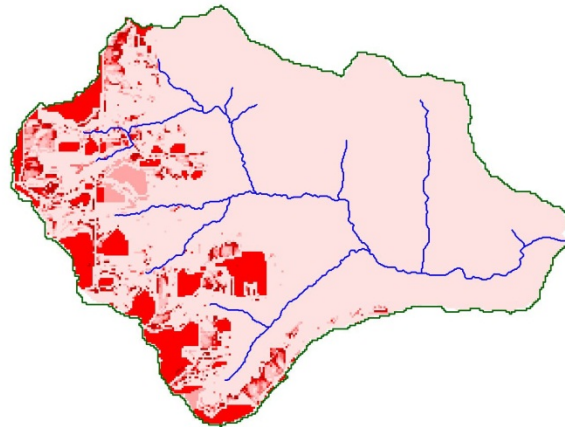
Spring



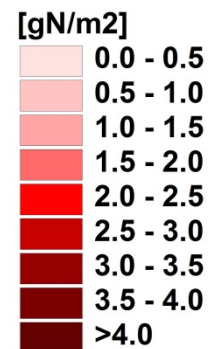
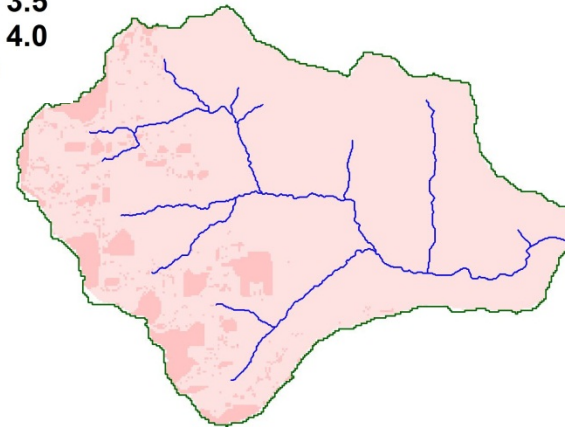
Summer



Fall

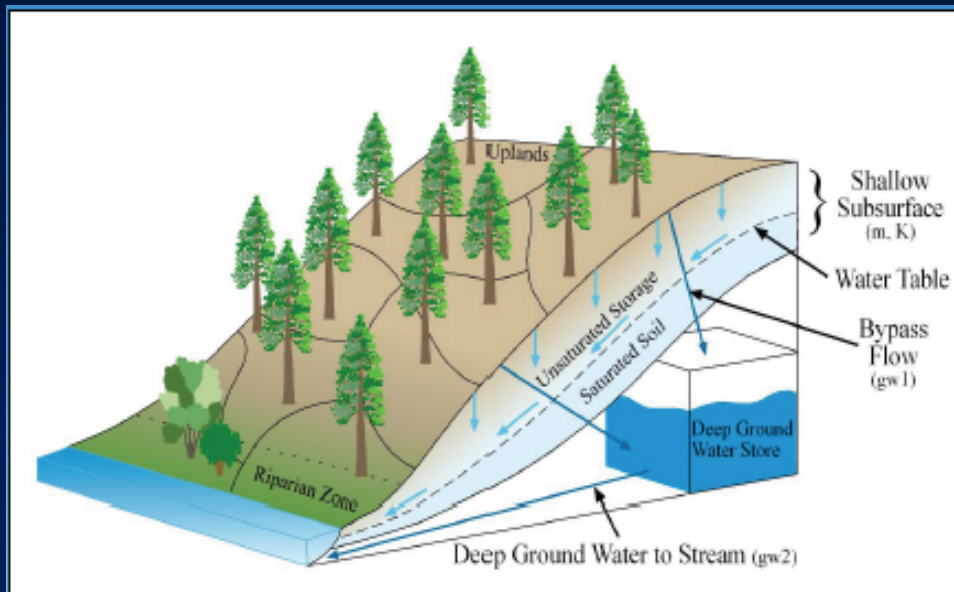


Winter



Modeling Challenges and Opportunities

- Account for spatial variability and local heterogeneity.
- Incorporate spatio-temporal linkages between hillslopes, riparian zones and streams.



Conclusions

- Examining land-use effects is important for prioritizing N reduction efforts.
- Approaches based on hydrologic connectivity could improve coarse-scale models and could be used for targeting forest and buffer preservation and restoration.
- Spatial process-based models are an important tool for predicting and understanding the spatial and temporal variation in N cycling.

Acknowledgments

- UD: Joanna York and students in watershed hydro-ecology class.
- Virginia Tech: Conrad Heatwole; Jim Lawrence; Cully Hession; Mary Leigh Wolfe; Brian Benham; Kurt Stephenson.
- RHESys developers: Christina Tague (UCSB), Larry Band (UNH) and others.

