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

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Healthy Watersheds
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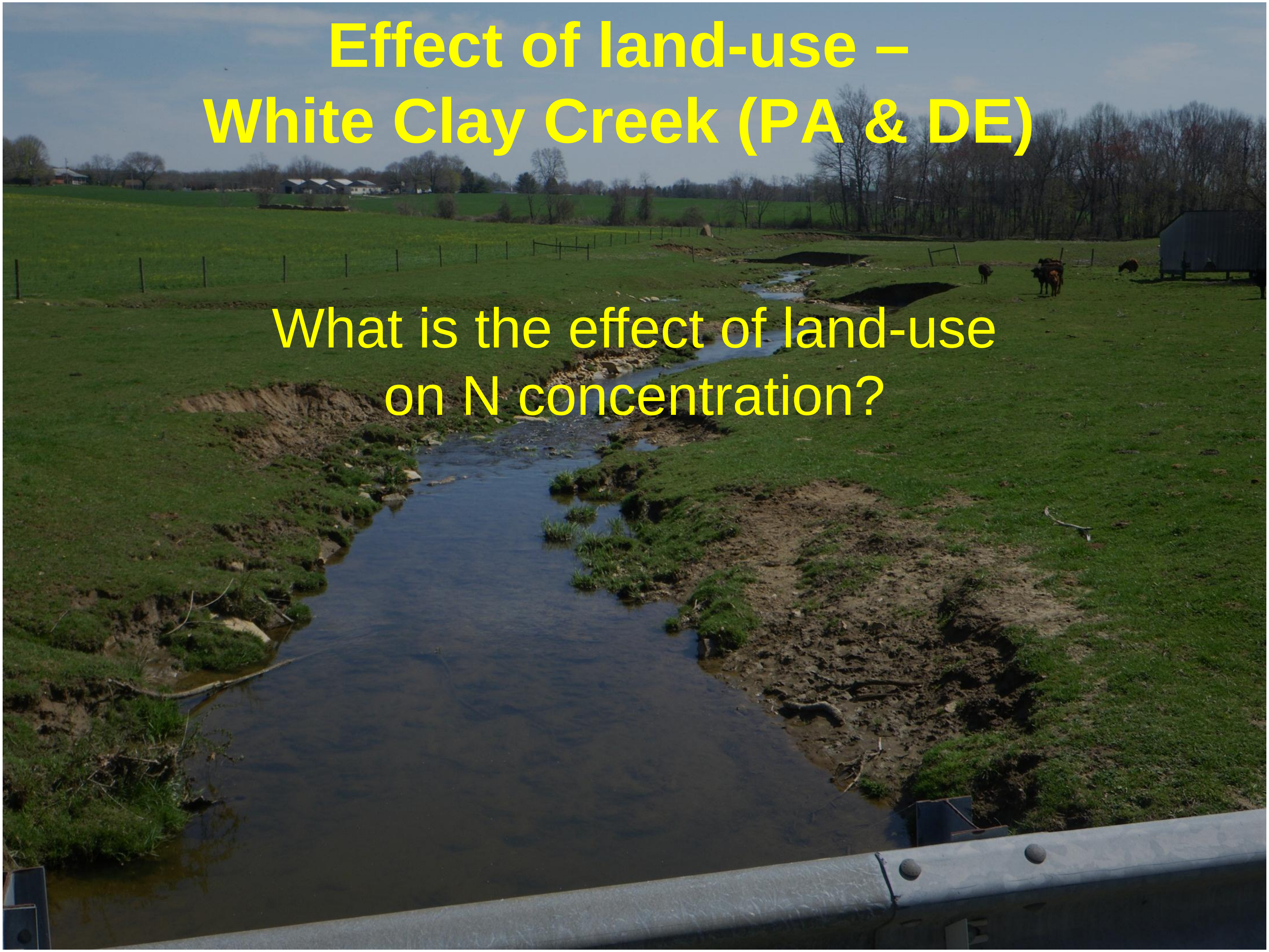
Questions

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

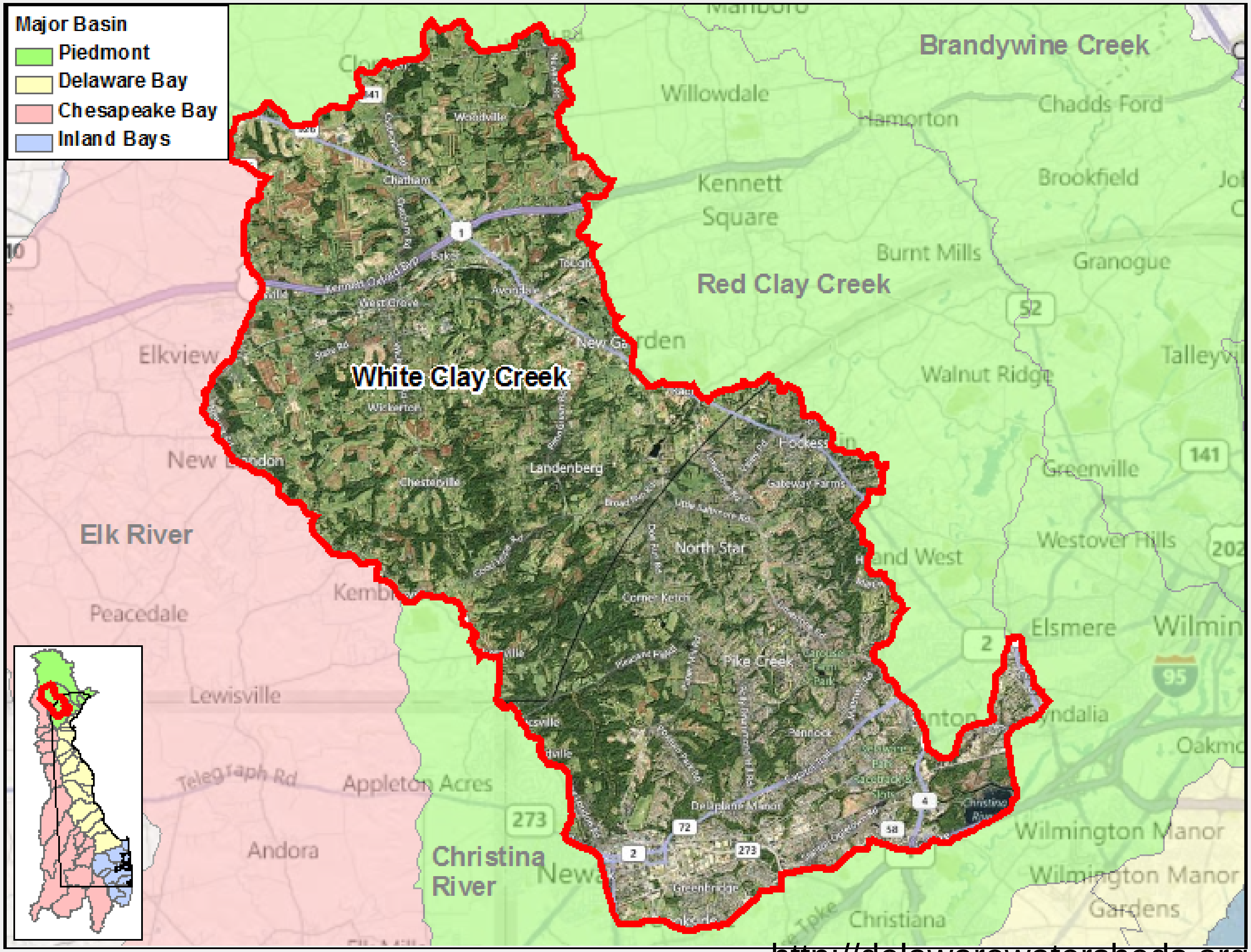
- Effect of land-use – White Clay Creek (PA & DE)
- Effect of spatial organization – Opequon Creek (VA & WV)
- Spatial process-based modeling – Baisman Run (MD)

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



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

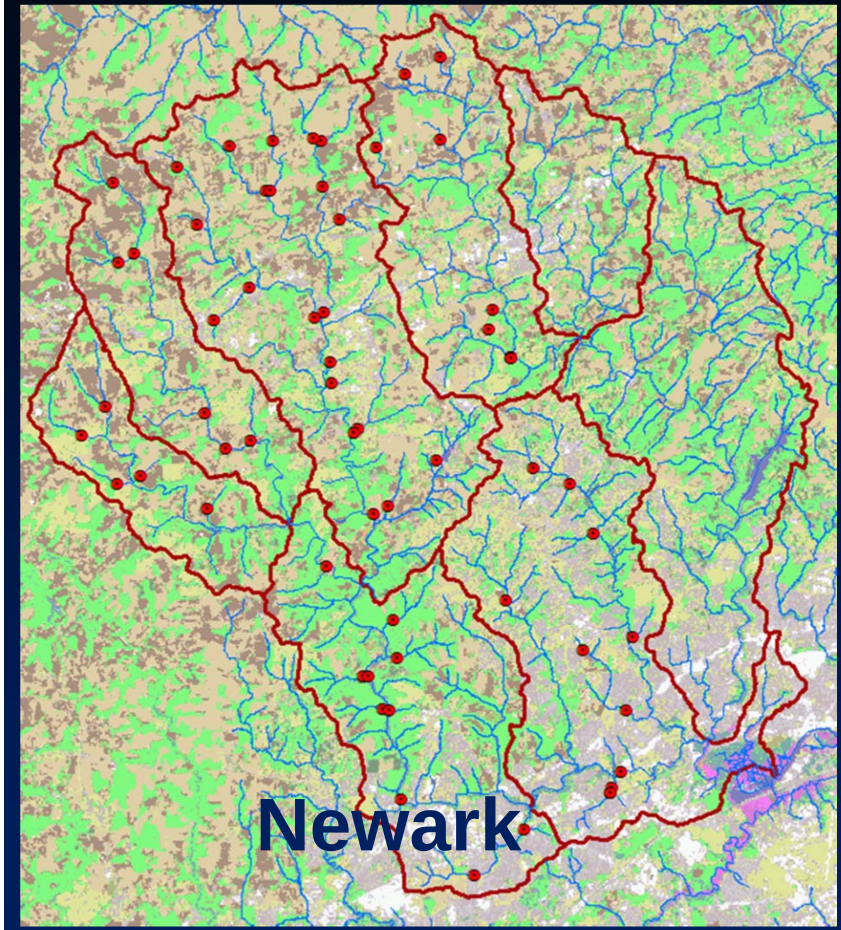
White Clay Creek Watershed



http://delawarewatersheds.org/

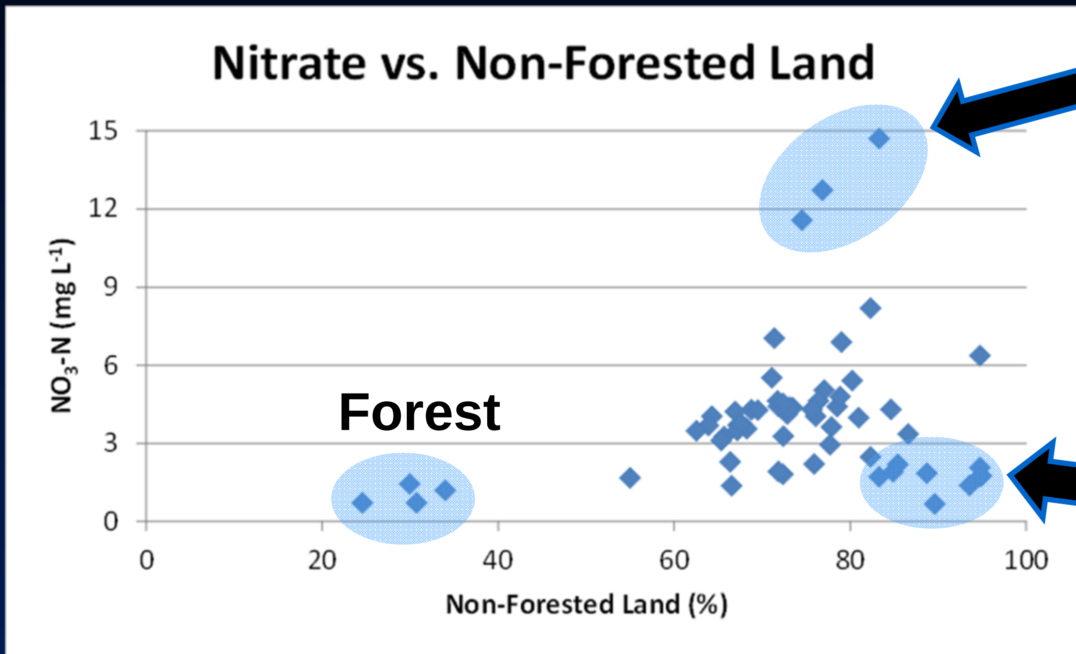
~280 km^2

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”

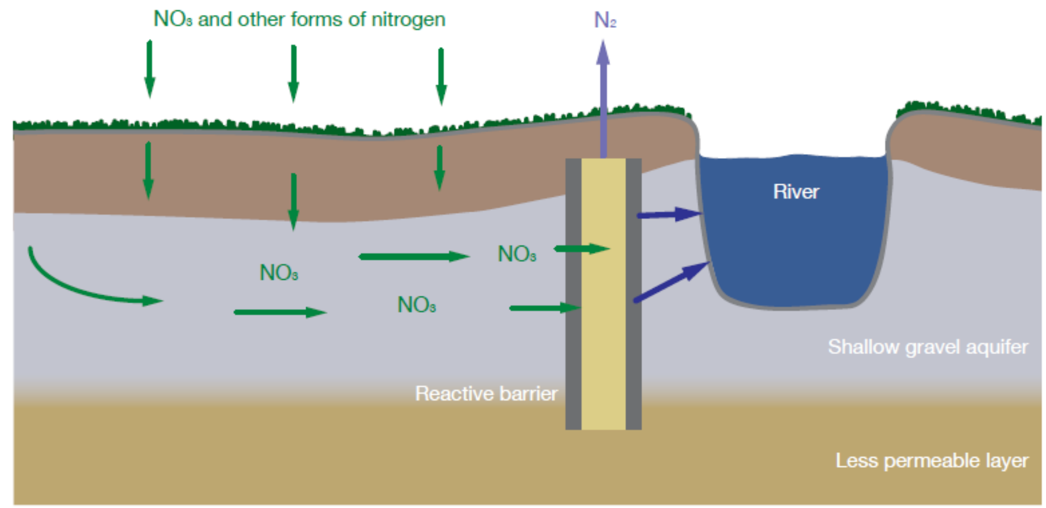


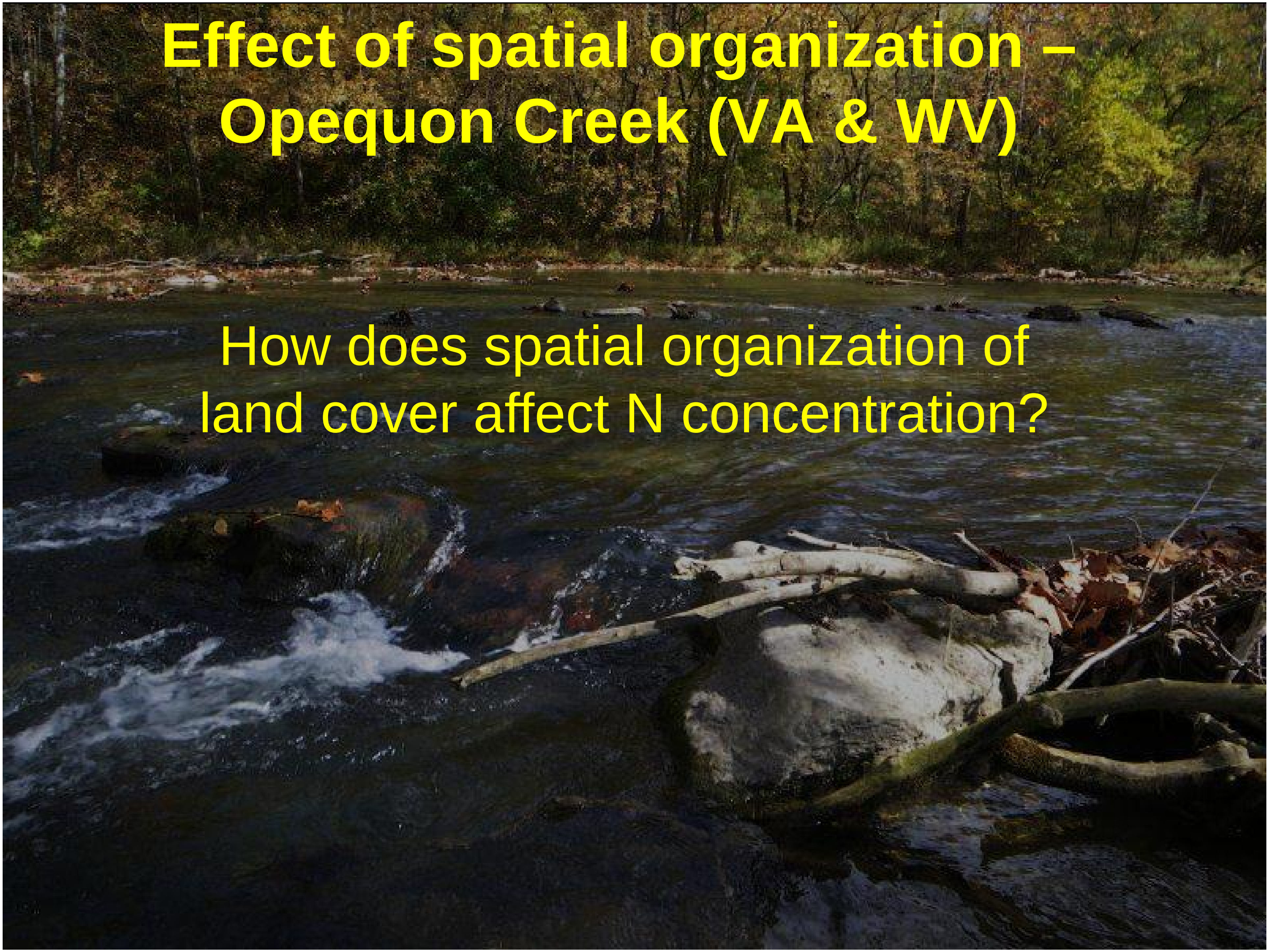
Figure 2.1: Schematic diagram of a PRB for treating nitrate-contaminated water.

(http://www.nitrabar.eu)

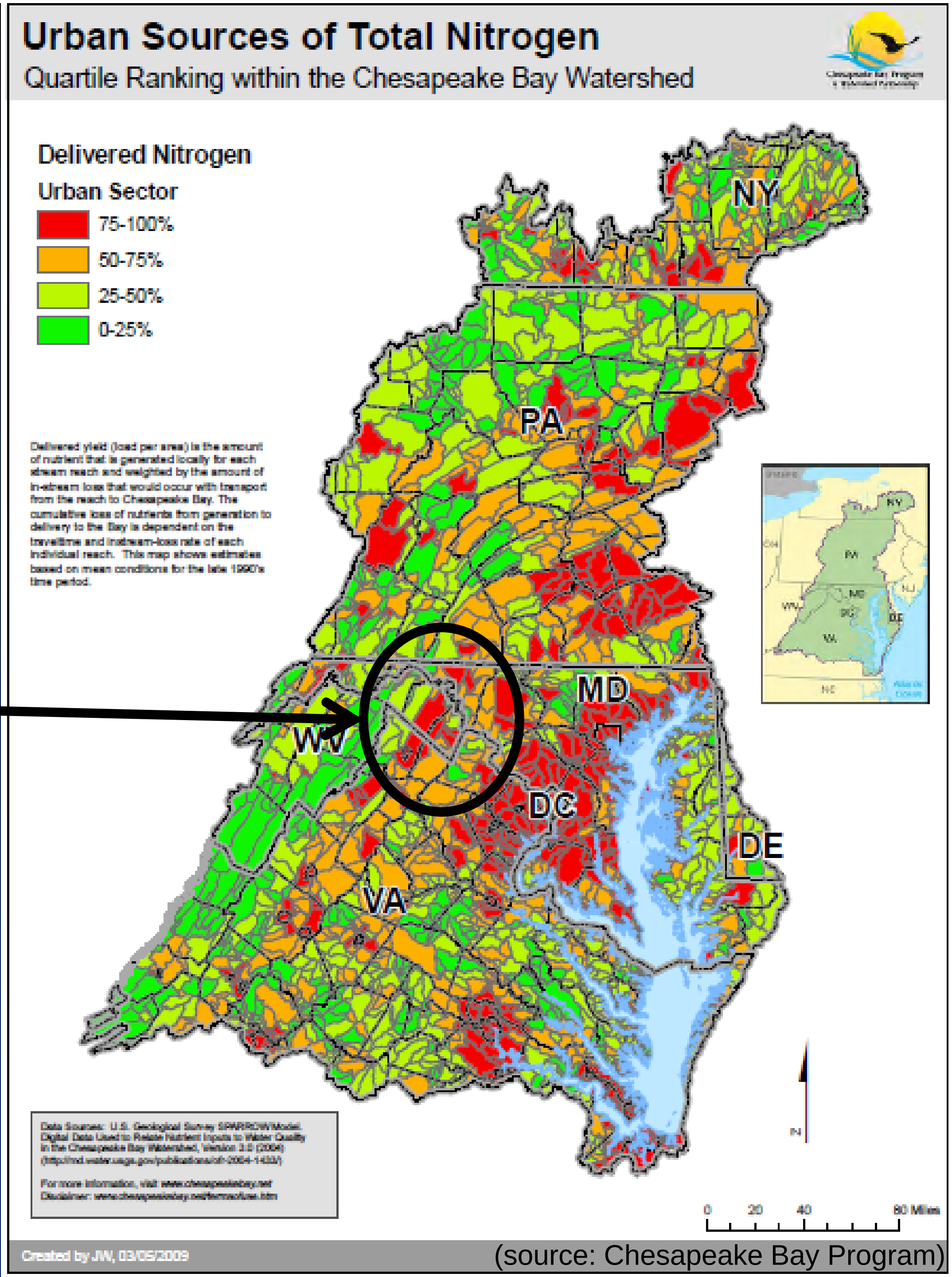
- Organic carbon substrate → immediate N reduction
- Potentially treat surface water → no long lag times associated with most BMPs → immediate lowering of stream N

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

How does spatial organization of land cover affect N concentration?

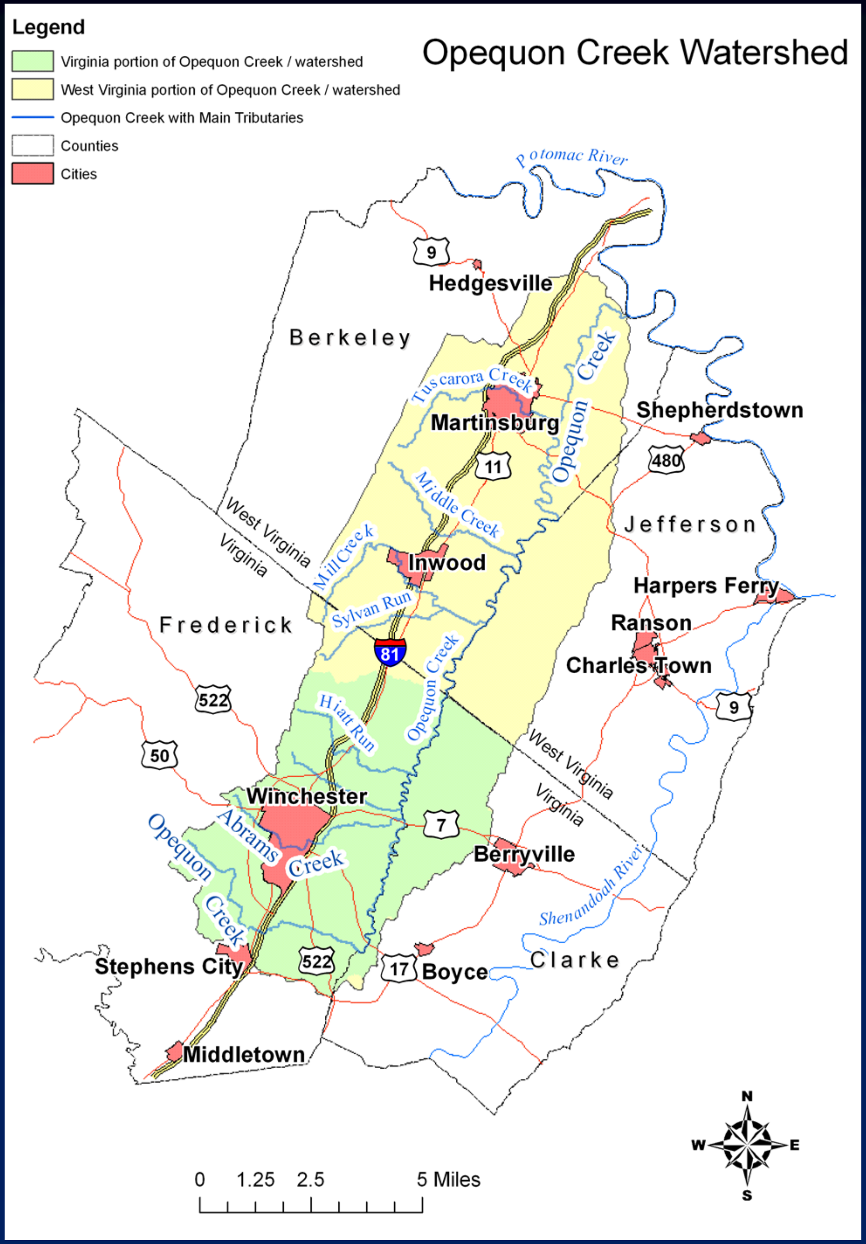


Opequon Creek watershed



(source: Chesapeake Bay Program)

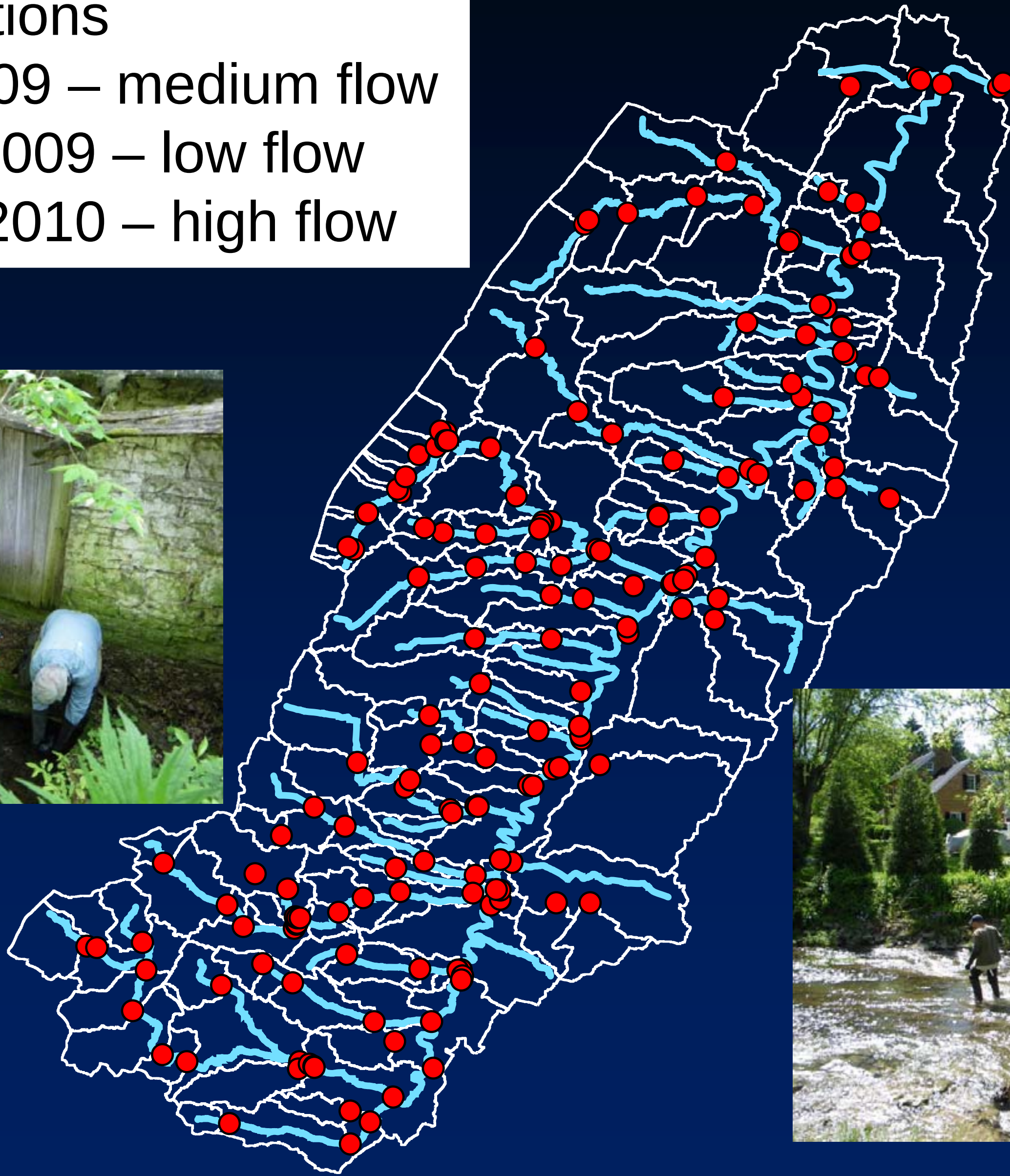
Opequon Creek Watershed



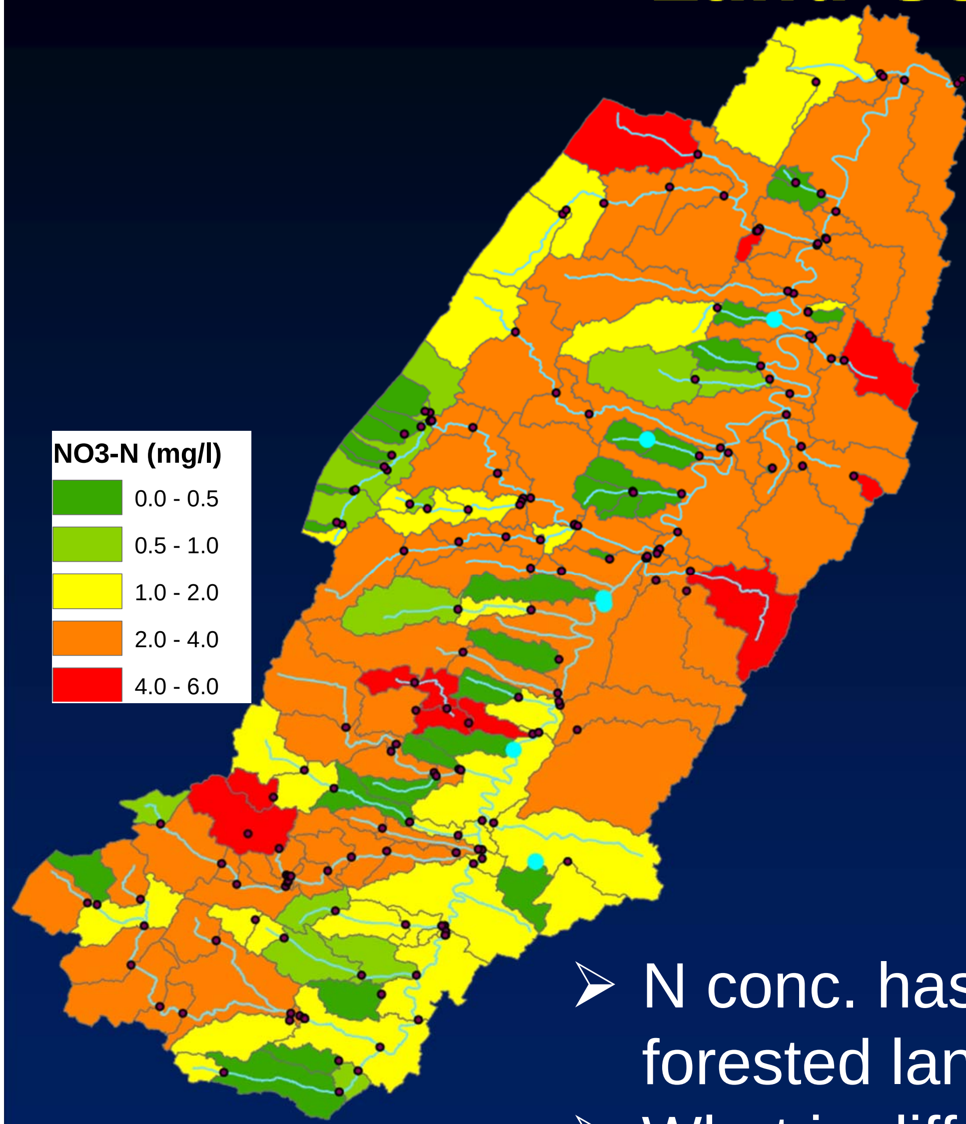
- ➢ 890 km^2
- ➢ Mixed land use, with rapid conversion of agricultural to residential.
- ➢ Impairments of nutrients, sediment and bacteria.
- ➢ Source of nutrients:
  - Point sources
  - Agricultural NPS
  - Urban NPS

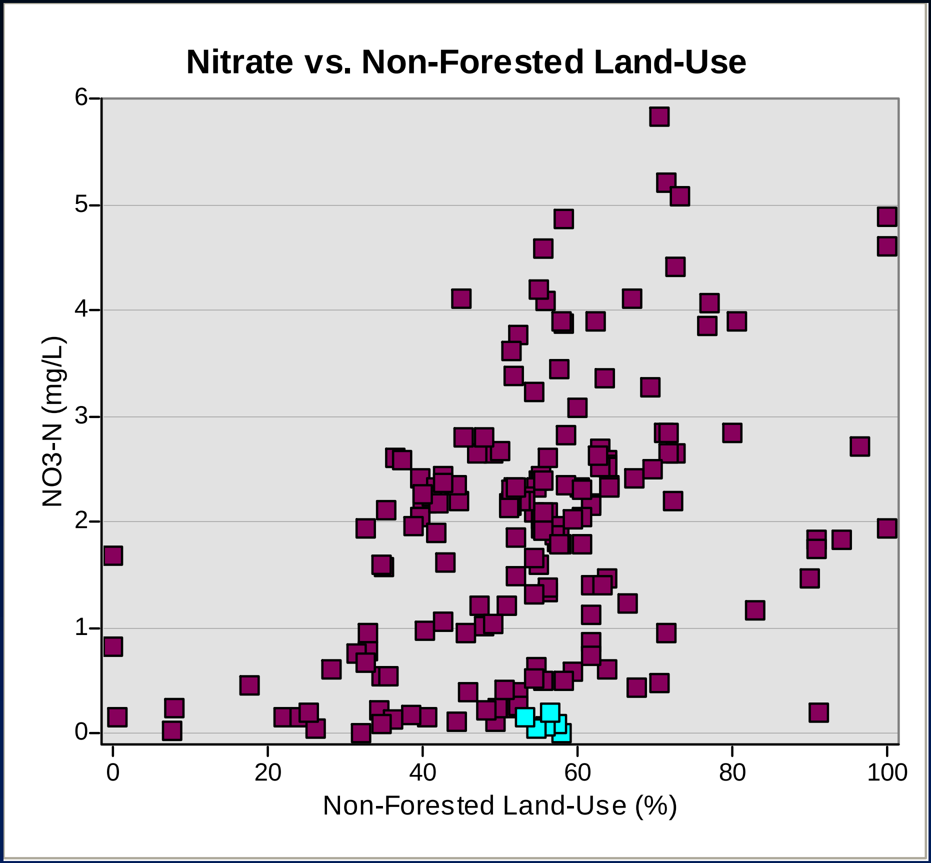
Snapshot Sampling

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



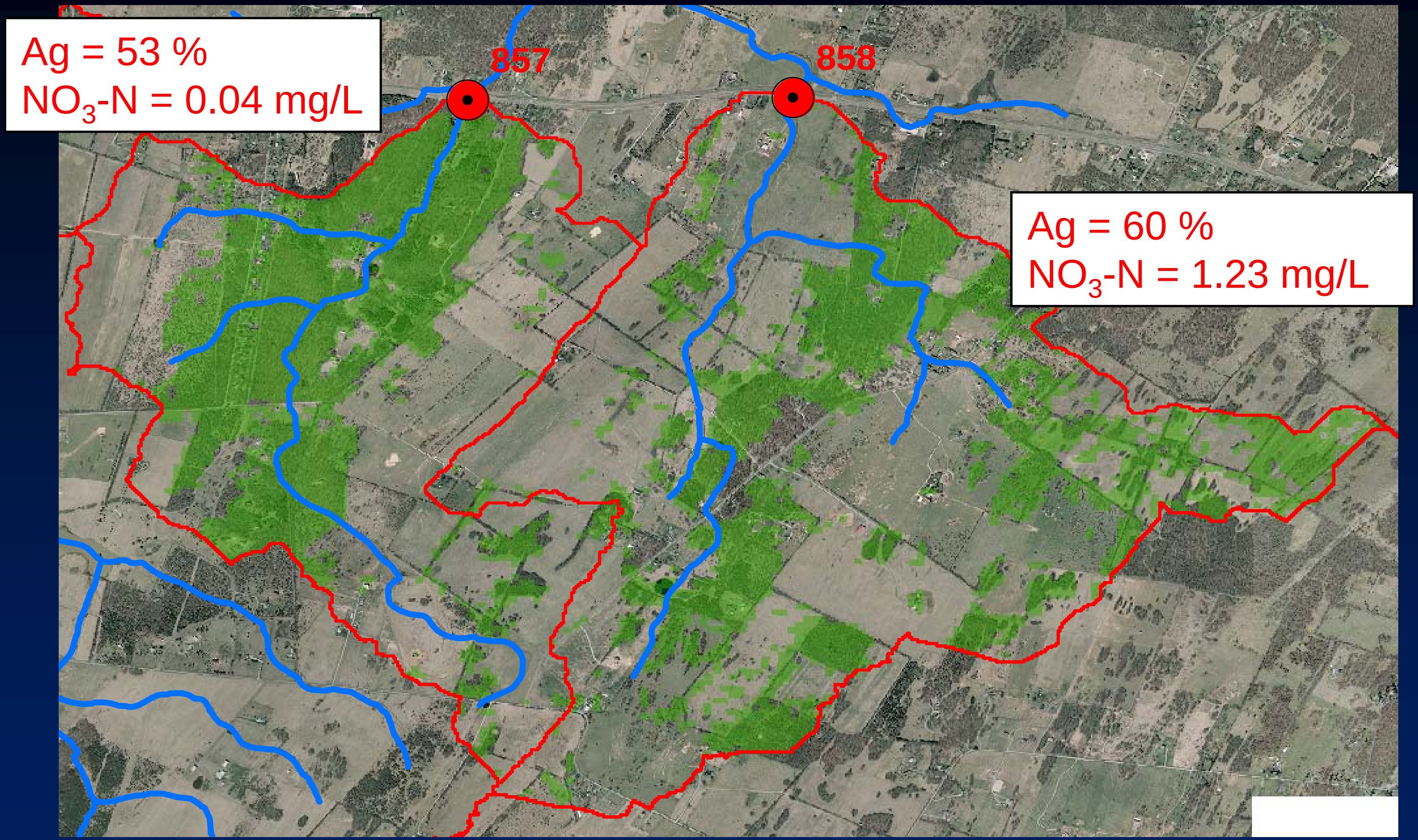
Land-Use Effects





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

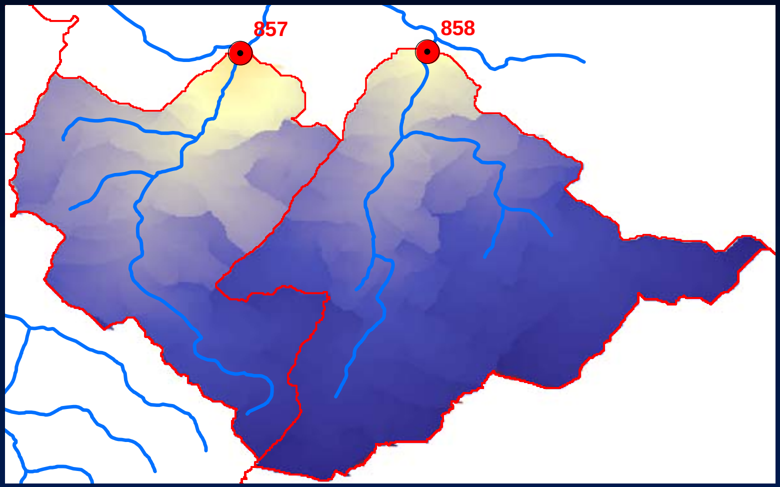
Land-Use Effects



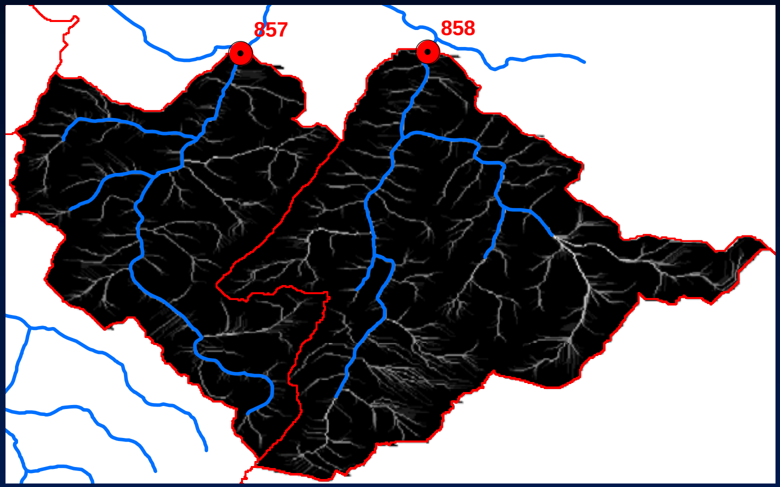
- Similar fractional land-use, but distinct N conc.
- Lumped categorization might not capture relevant N removal processes.

Spatial Metrics of Hydrologic Connectivity

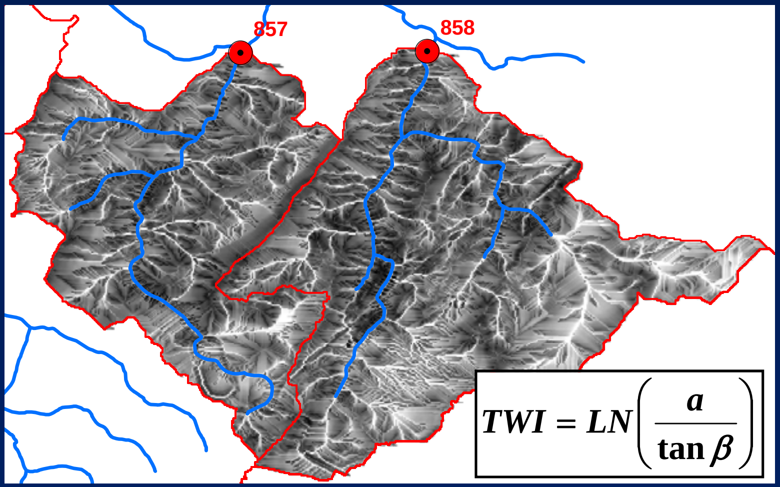
Flow Distance



Flow Accumulation



Topographic Wetness Index



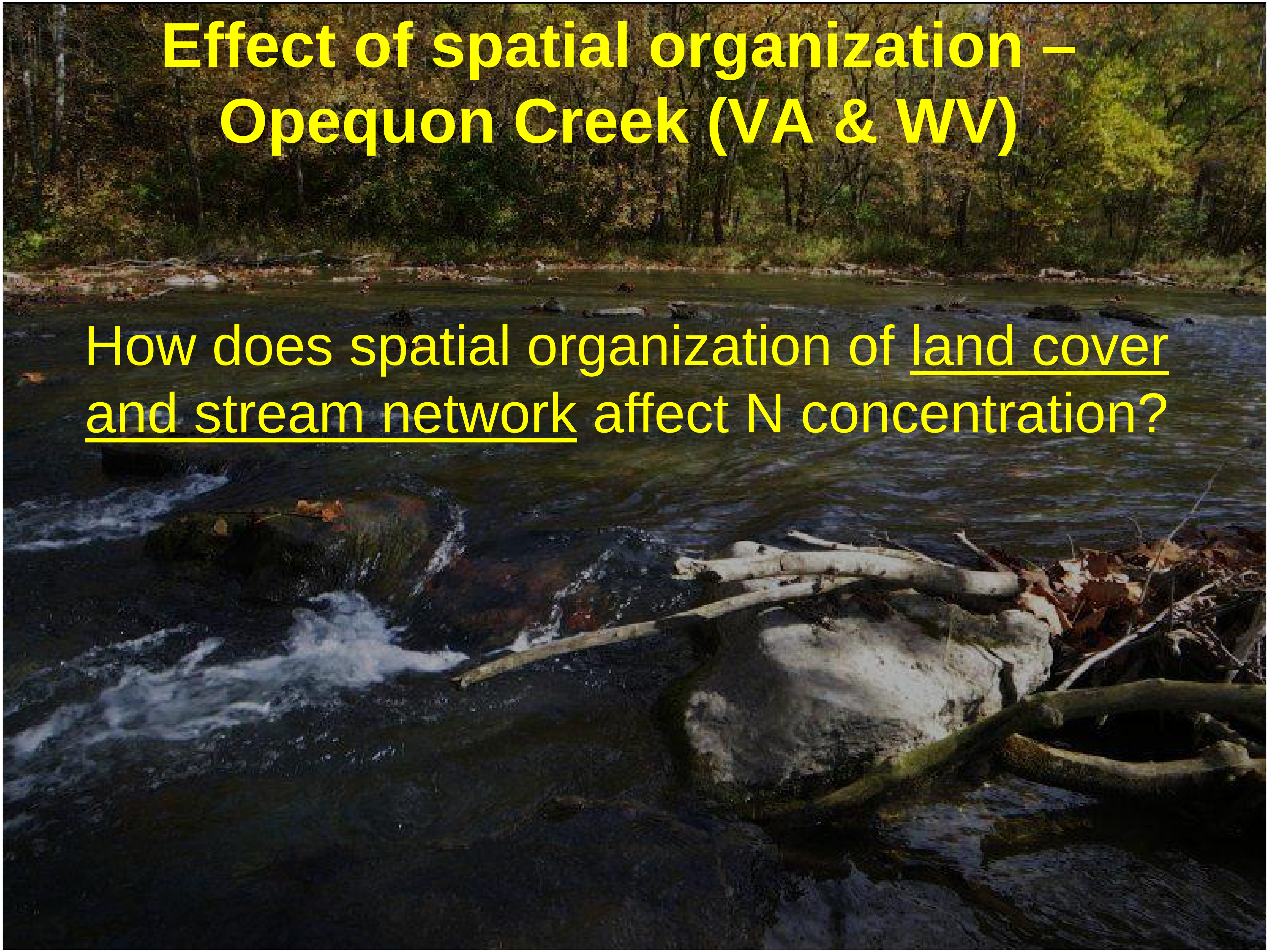
Spatial Weighting to Predict 'Effective' Land-Use

Station	NO_3-N	Non-Forested Land-Use (%)			
(-)	(mg/L)	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

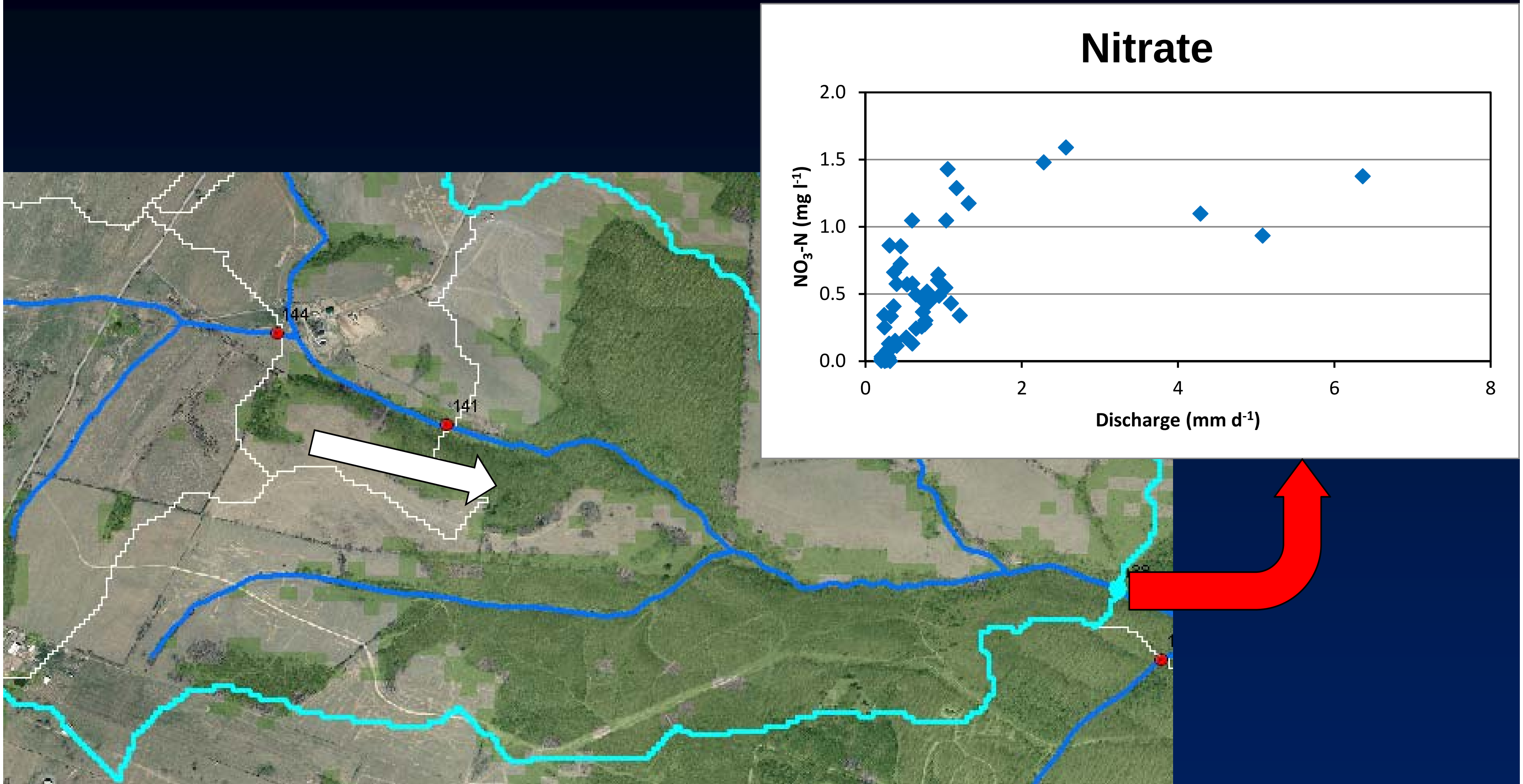
- Spatial weighting using flow accumulation improves predictive ability of land-use effects on NO_3 concentration.
- Accounting for spatial factors is critical for watershed modeling and mitigation, conservation and restoration efforts.
- Models currently used for decision-making are based on lumped 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 <u>land cover and stream network</u> 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.

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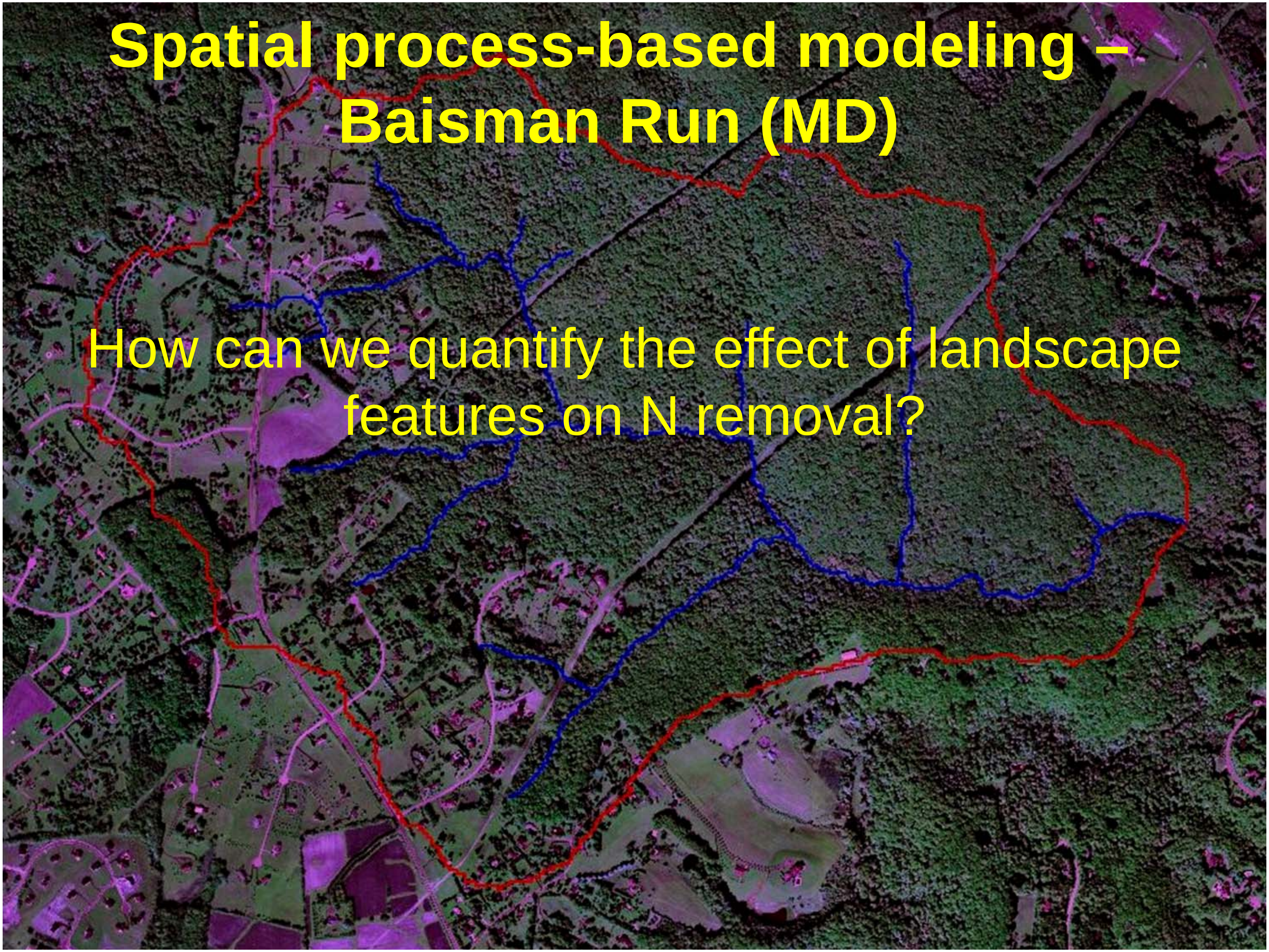
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, G04016, doi:10.1029/2009JG001017, 2009

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. Kenworthy[7]

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.

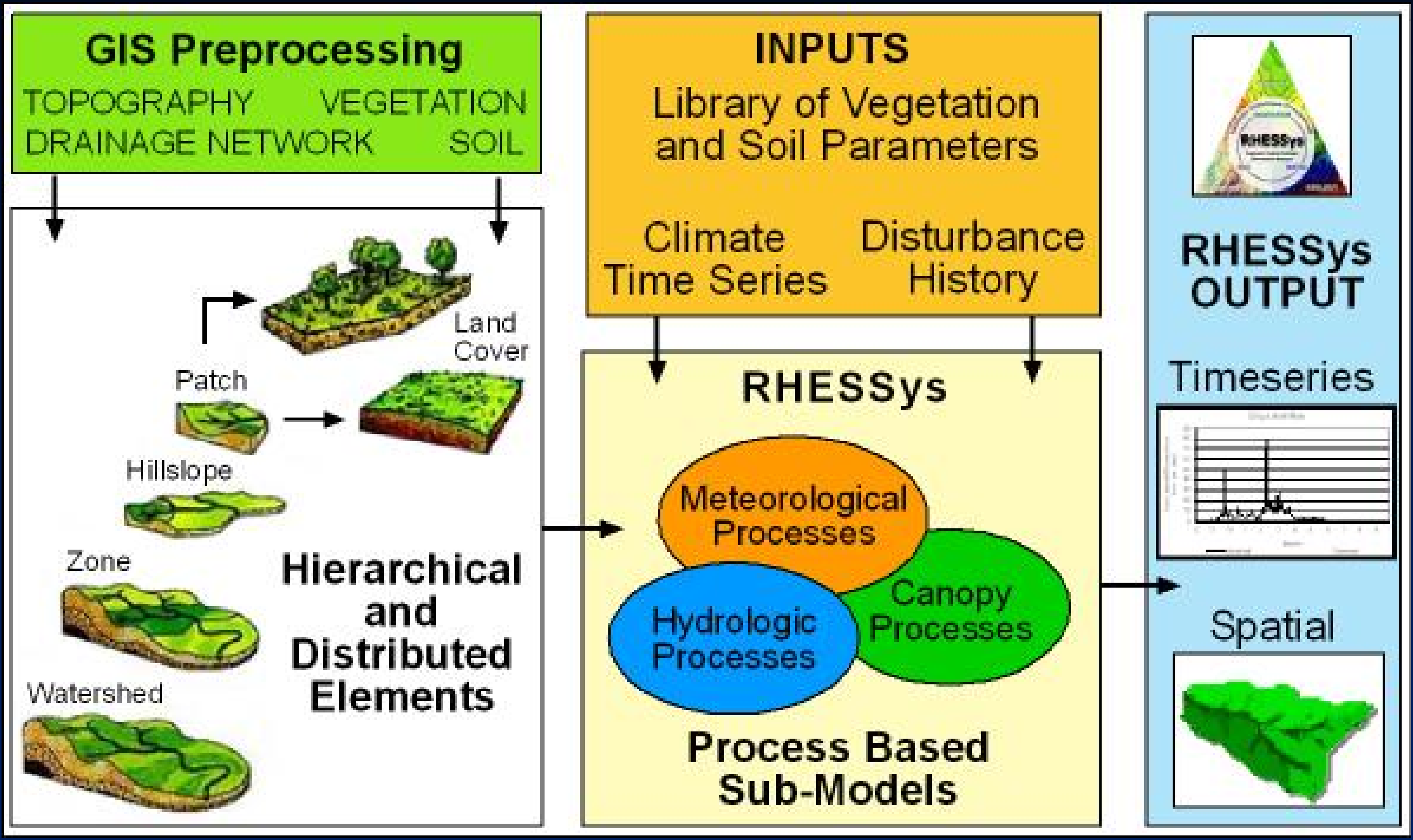
Models need to be parsimonious (simple) and should not suffer from equifinality (right result for wrong reason).

Spatial process-based modeling of N removal

Regional Hydro-Ecological Simulation System

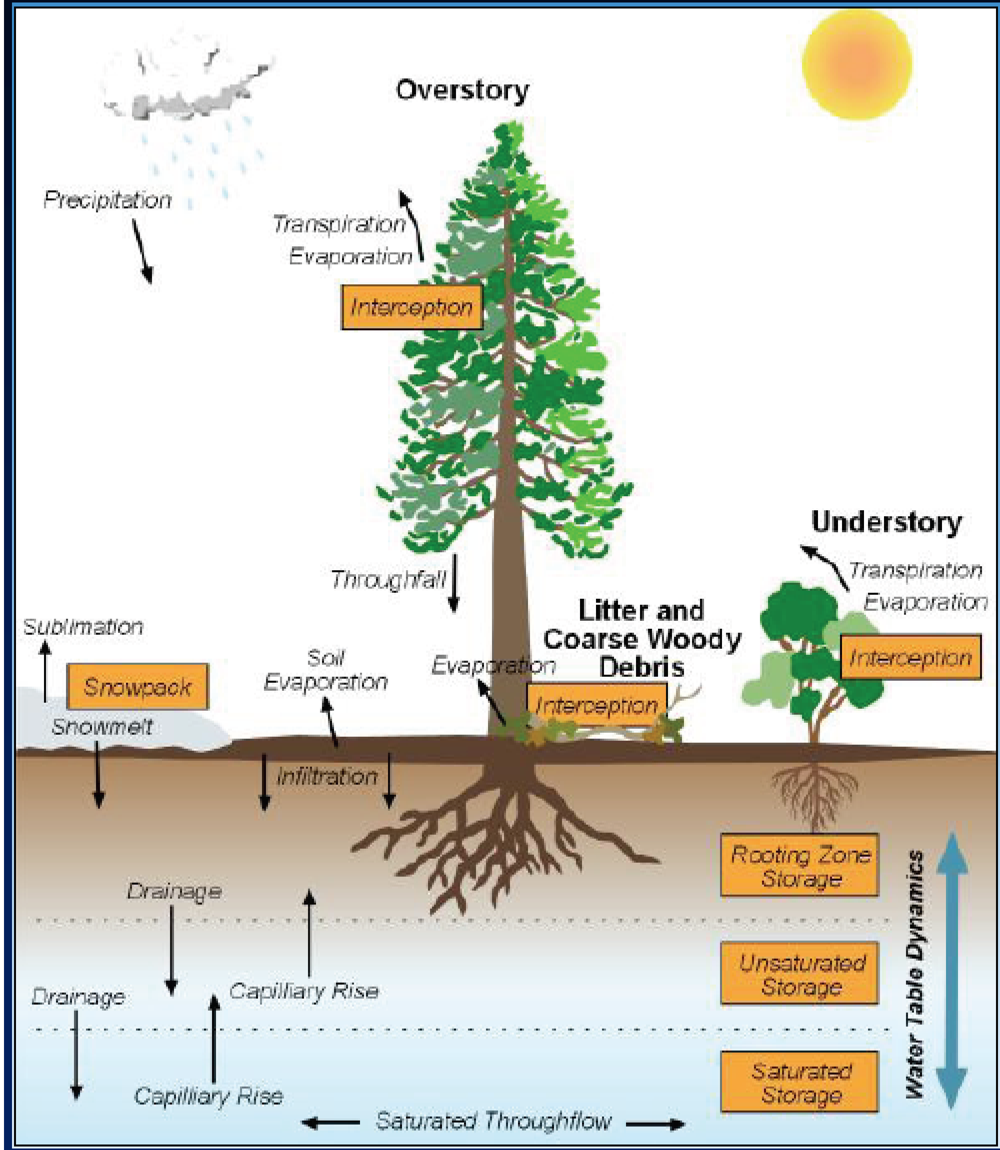
http://fiesta.bren.ucsb.edu/~rhessys/
Tague and Band, 2004

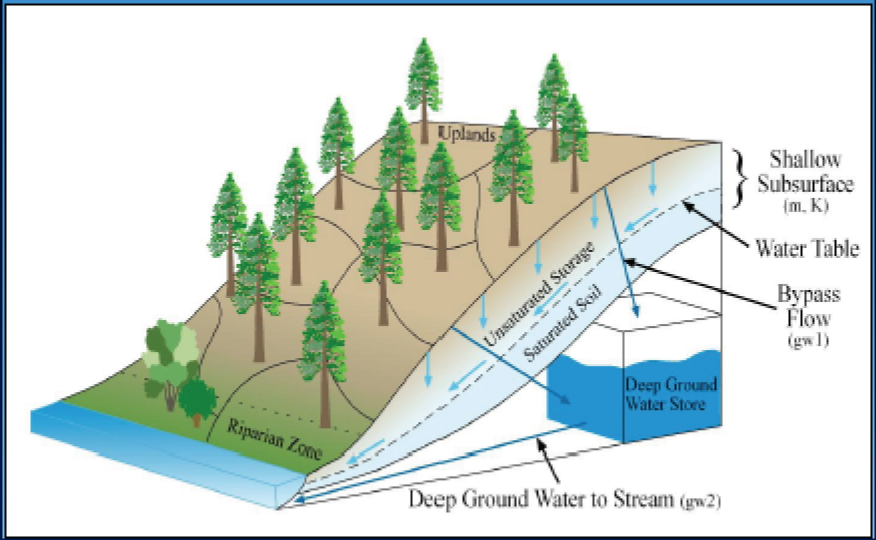
Computational structure of RHESSys



(source: C. Tague)

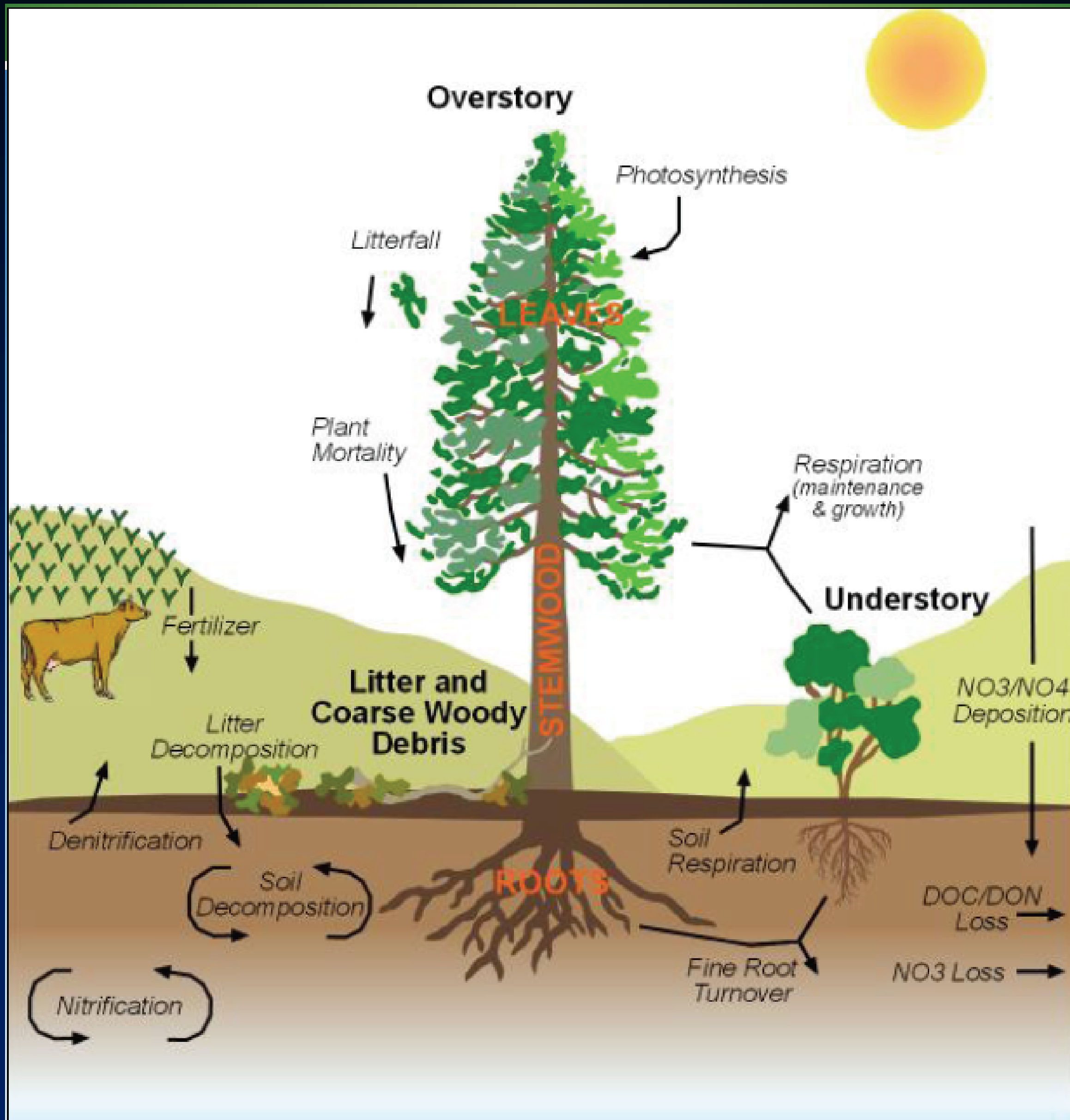
Vertical and lateral drainage in RHESSys





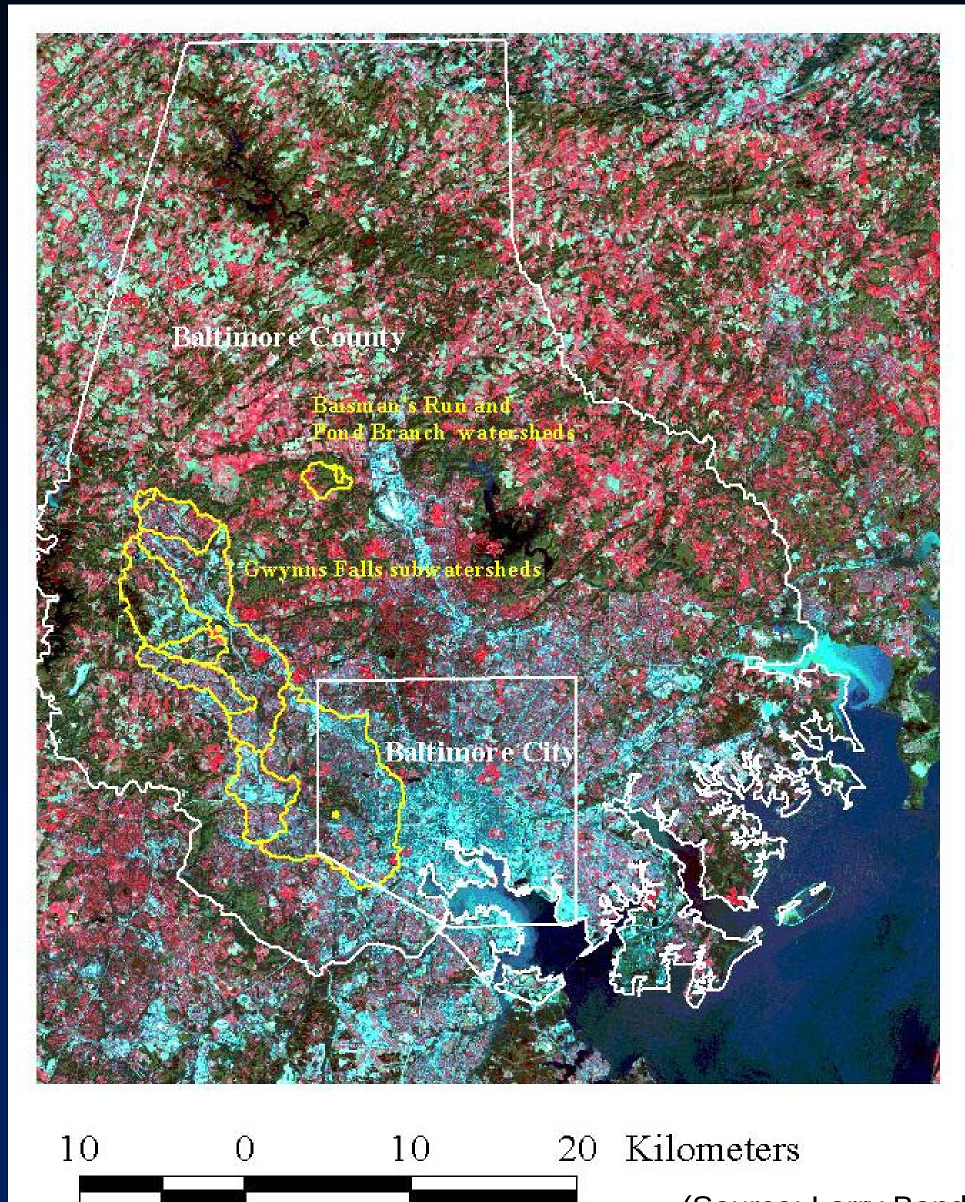
(source: Christina Tague

Carbon and nitrogen cycling in RHESSys



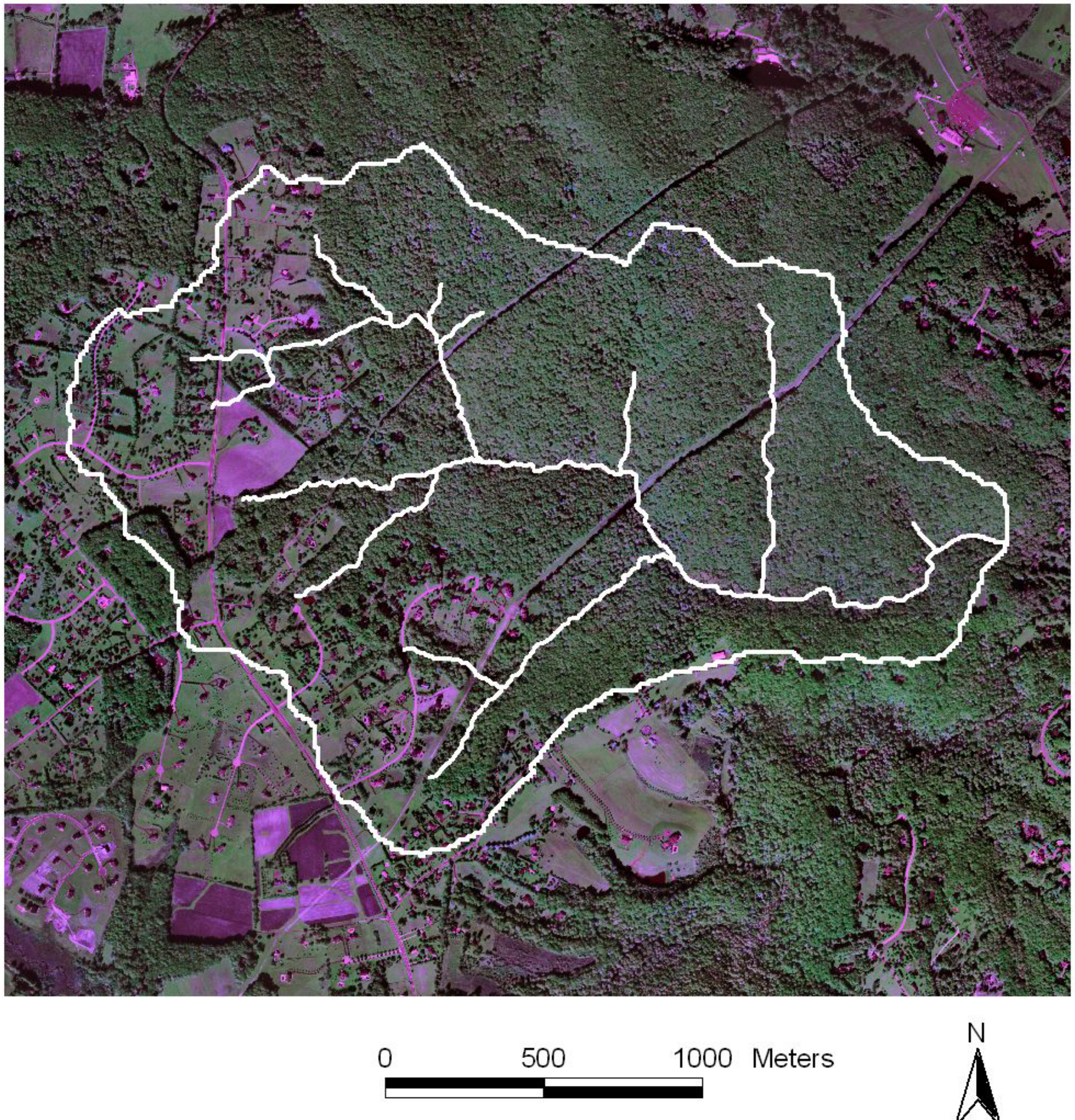
(source: Christina Tague)

Baltimore Ecosystem Study LTER



(Source: Larry Band)

Baisman Run Watershed



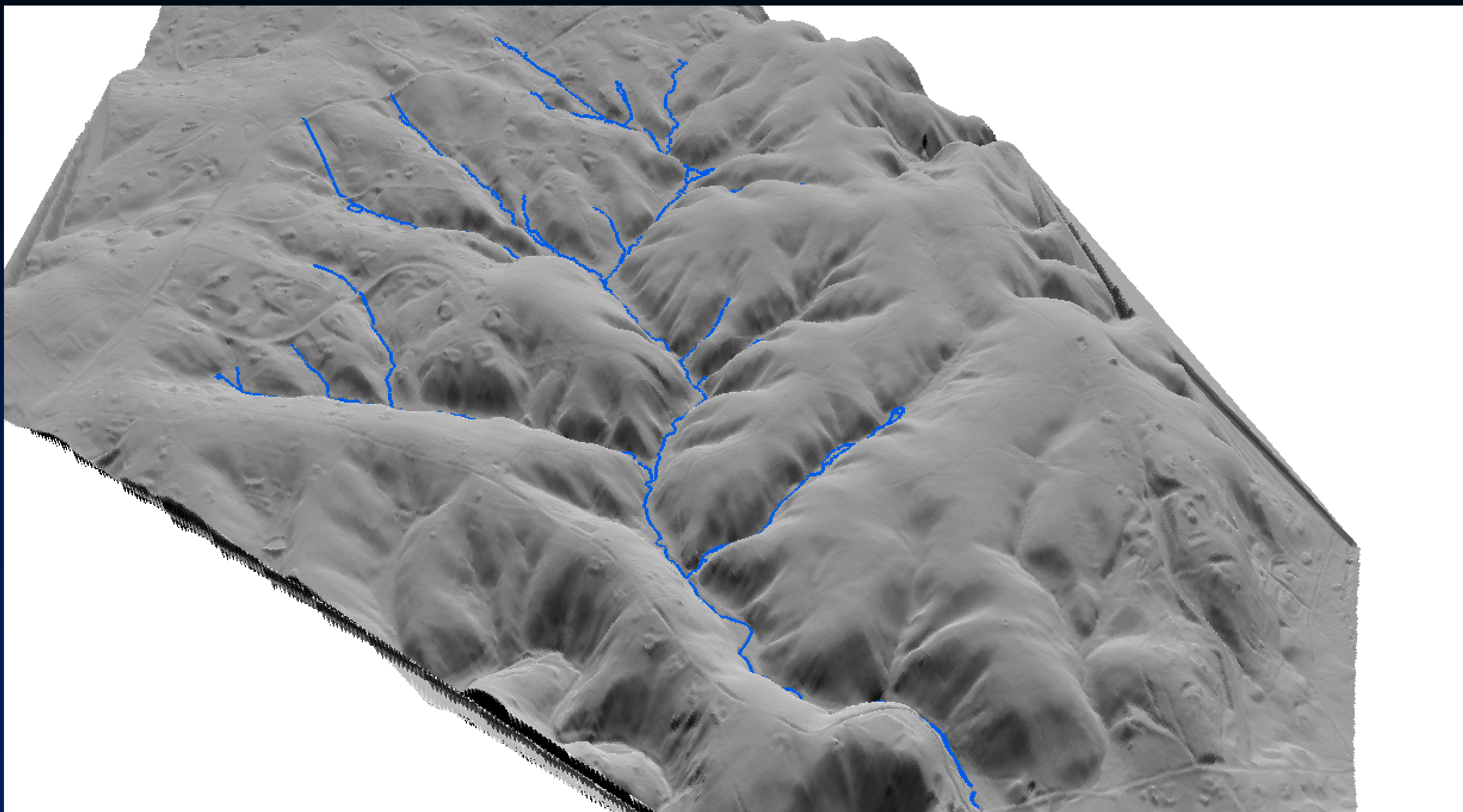
(false color image using EMERGE digital aerial imagery; RGB = 3,1,2)

- 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.

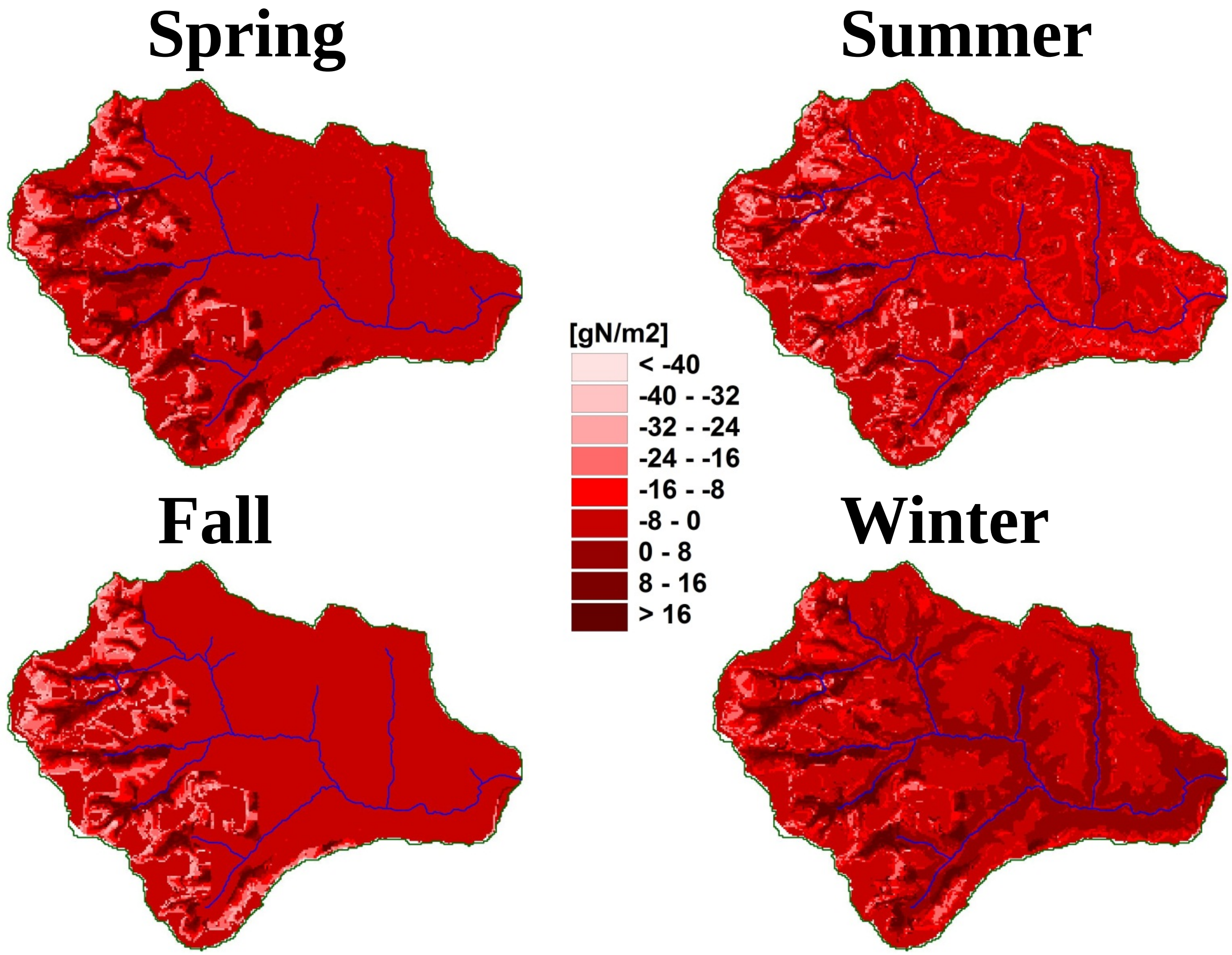
N fluxes (g N ha^{-1} d^{-1})

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

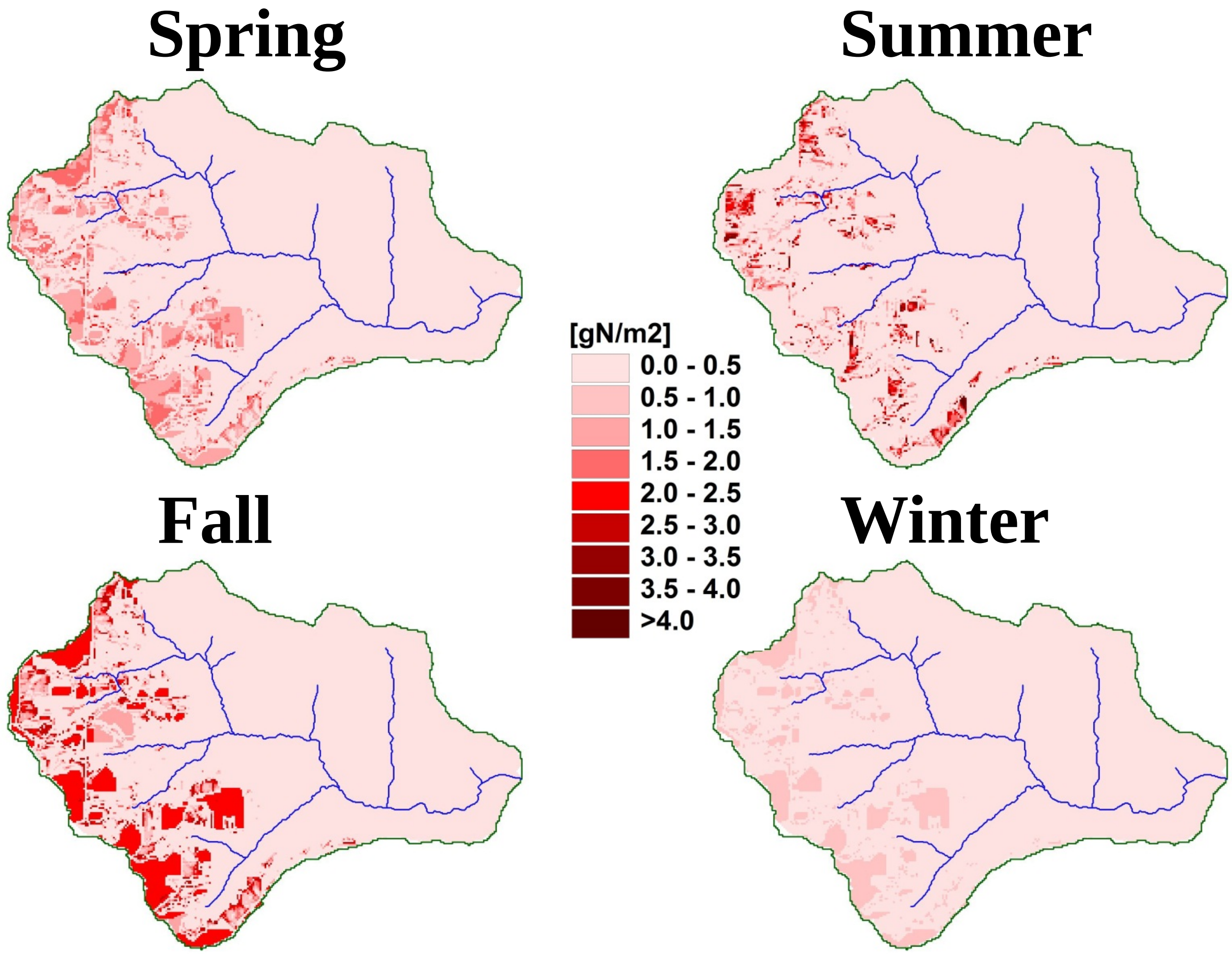
(Claessens et al., 2009 – JGR)



Seasonal Net Nitrate Flux (2001)

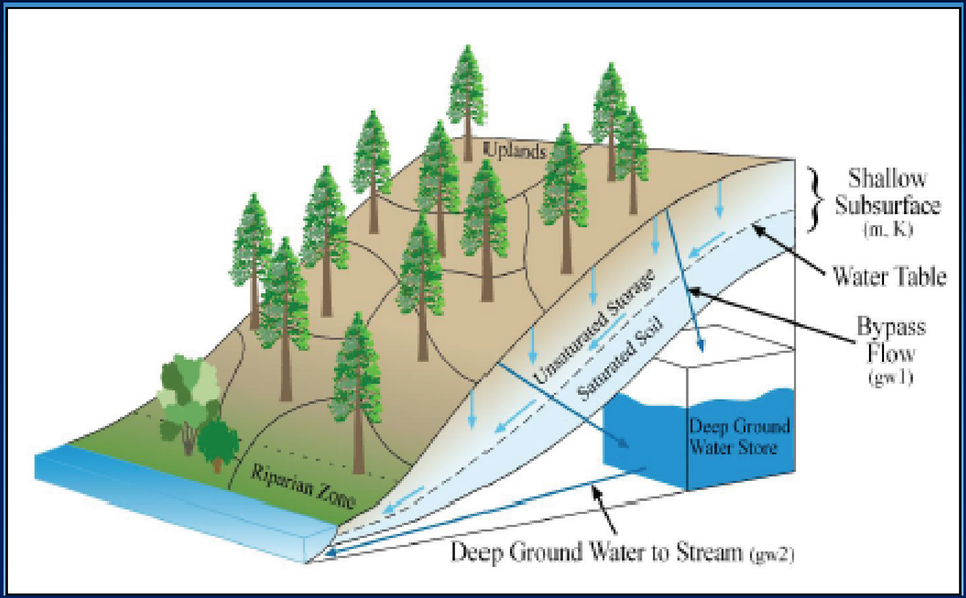


Seasonal Denitrification (2001)



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.
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- RHESSys developers: Christina Tague (UCSB), Larry Band (UNH) and others.

National Fish and Wildlife Foundation