Toward Innovative Approaches for Improving Water Quality: Linking Eco-Hydrology with Ecosystem Services at the Watershed Scale

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University of Delaware

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Acknowledgments

- Students: Kelsey Moxey, Tom Santangelo, Sandra Demberger
- Dr. Joanna York, University of Delaware
- Chester County Conservation District

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- Delaware Environmental Institute (seed grant)
- Delaware EPSCoR (internship)
- Delaware Water Resources Center (internship)

Outline of Talk

- Background
- Study area and trends in water quality
- Effect of land-use and land management on nitrogen
- Mushroom farming and geospatial analysis
- Riparian buffers and geospatial analysis
- Monitoring of spatial and temporal patterns
- Alternative N reduction strategies

Background

- Agriculture and urbanization can lead to increased nitrogen export, which impacts downstream aquatic ecosystems.
- To reduce impact, best management practices (BMPs) are promoted (e.g., riparian buffers, stormwater retrofits).
- Implementing BMPs can require major investments, while there are still large uncertainties regarding their effectiveness and timeline of response.
- Key question: Are BMPs cost-effective?
- Examine approaches that are fast-response, innovative and cost-effective, perhaps applied within payment for ecosystem services scheme or nutrient trading.

Goals

1. Gain detailed understanding of spatial and temporal variation of nitrogen export at subwatershed scale
   - Q: Where are N hotspots and what are the legacies?
   - Q: What are the sector contributions (ag, urban, etc.)?
   - Q: What time scales of continuous sensing best capture and explain critical N process controls?
2. Evaluate N reduction benefits of current strategies
   - Q: What is the potential for N removal using riparian buffers for areas targeted for restoration?
3. Assess feasibility of alternative N reduction strategies
   - Q: What is the technical, economic and management feasibility of using bioreactors and other innovative nutrient reduction measures?
   - Q: How can we develop a watershed approaches for ecosystem services vs. farm-based approach?

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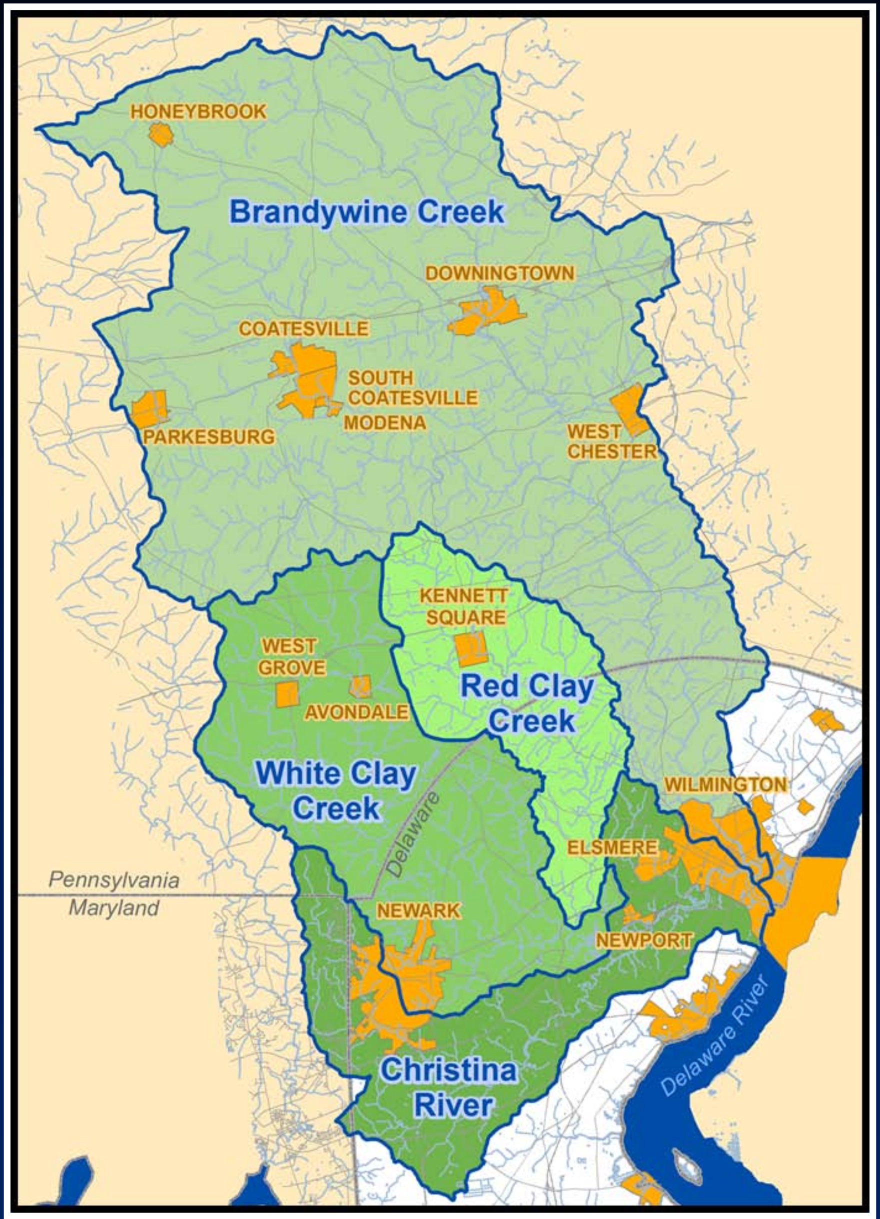
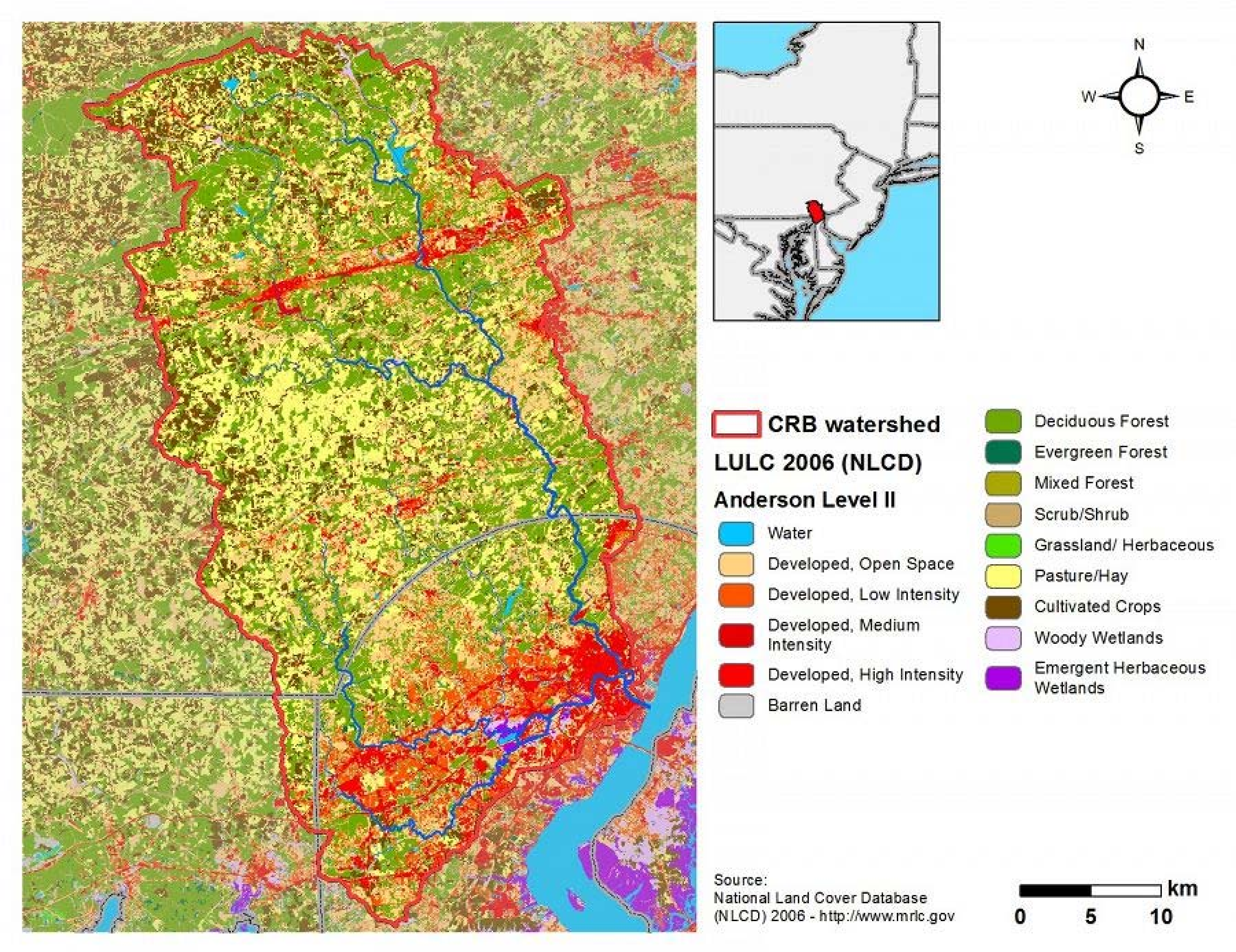
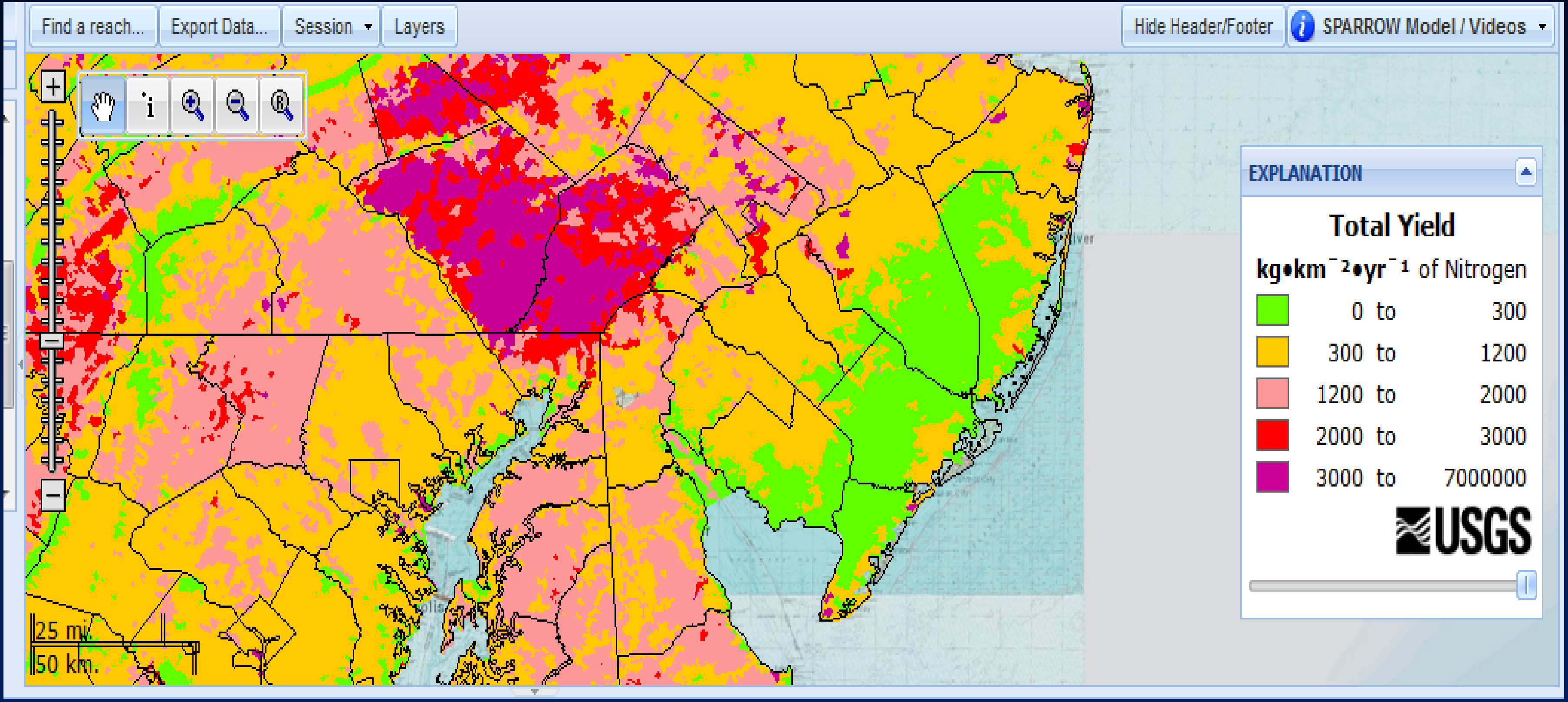
Study Area – Christina River Basin

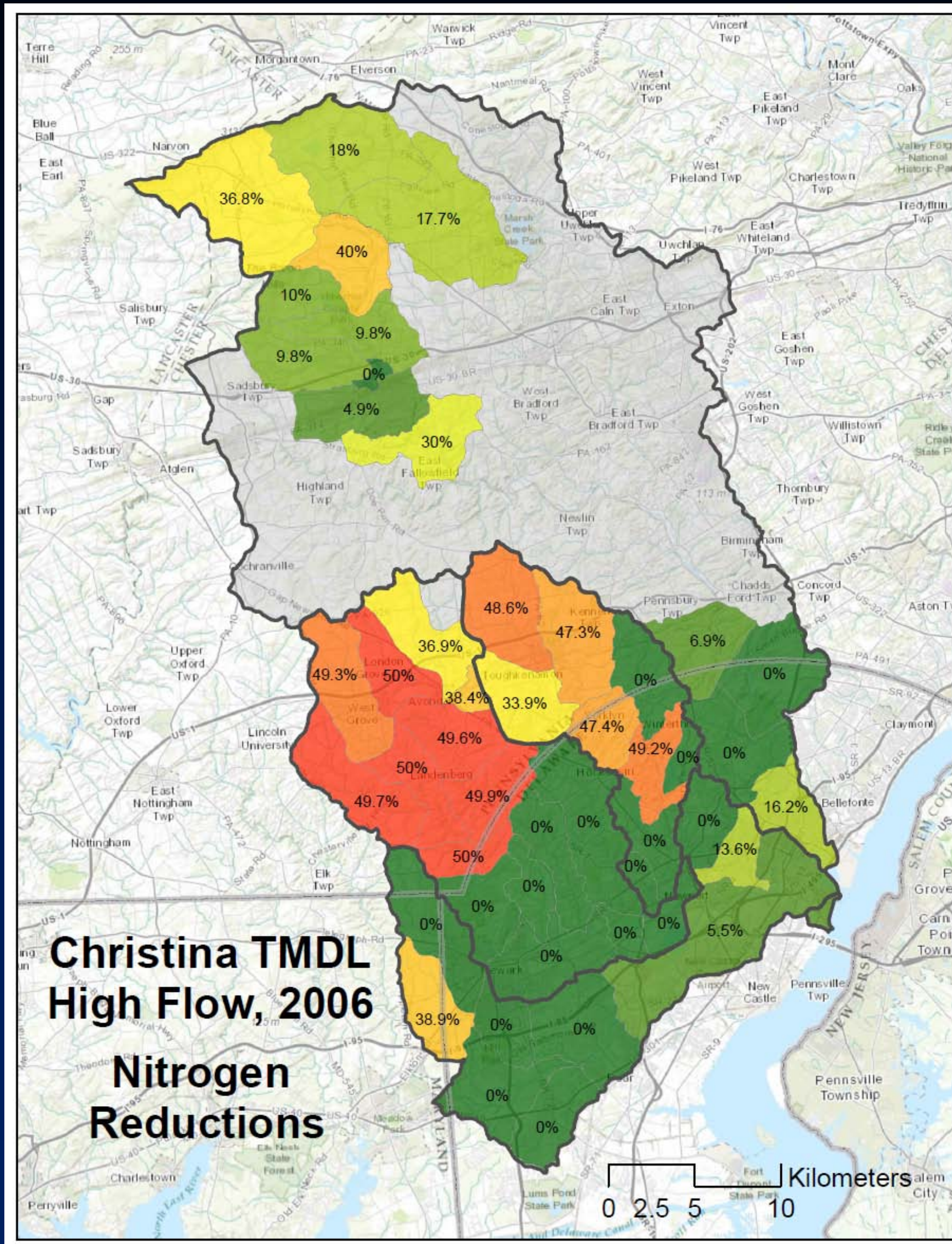



N
W
E
S
CRB watershed
LULC 2006 (NLCD)
Anderson Level II
Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Scrub/Shrub
Grassland/ Herbaceous
Pasture/Hay
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands
Source:
National Land Cover Database (NLCD) 2006 - http://www.mrlc.gov
km
0
5
10

The Christina River Basin has some of the highest nitrogen loads in the East.



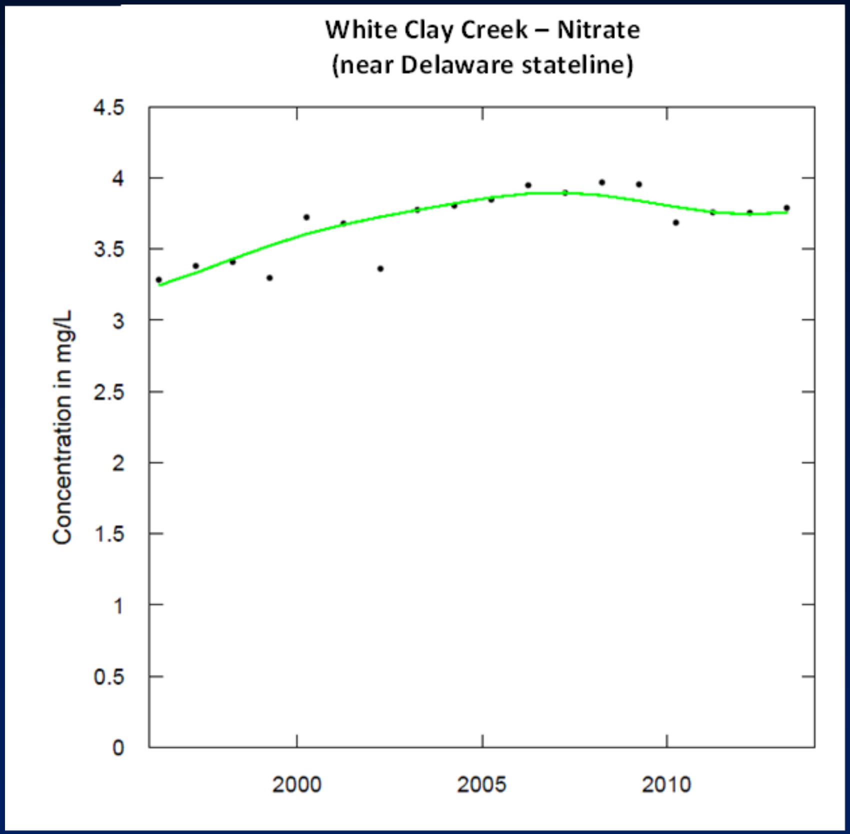
A pollution diet for the Christina River Basin

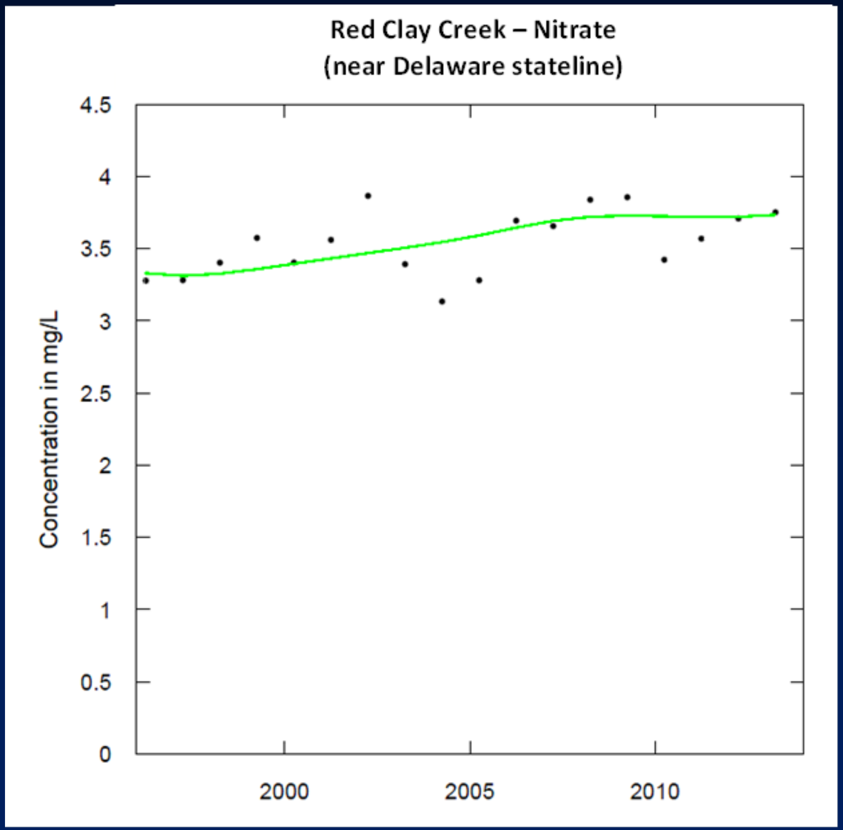


Our study concentrates on areas with the largest nitrogen TMDL reductions

A TDML is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that load among the various sources of that pollutant. (EPA website)

Long-term patterns of stream nitrate show that nitrate levels have not improved, illustrating the need for better N removal practices.



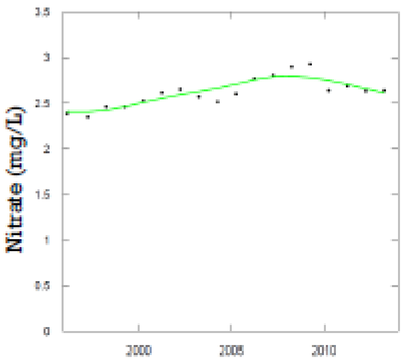


Flow-adjusted nitrate patterns, analyzed using WRTDS model (Hirsh et al., 2010) (Weighted Regression on Time, Discharge, & Season)

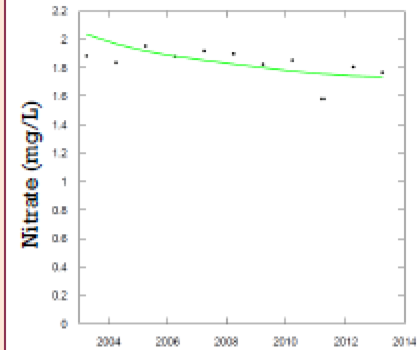
Regional Analysis

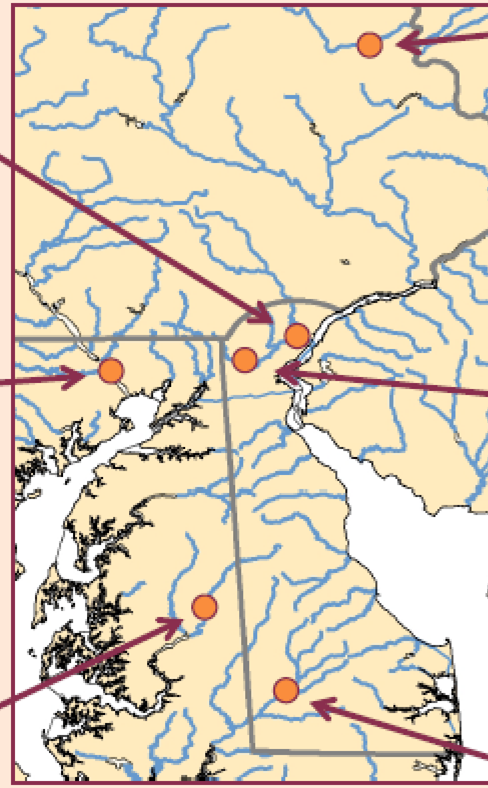
Model output of flow-normalized concentrations and long-term trend.

Brandywine Creek

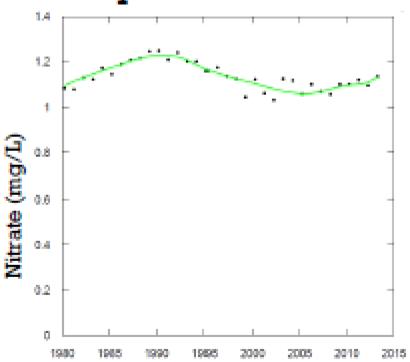


Lehigh River

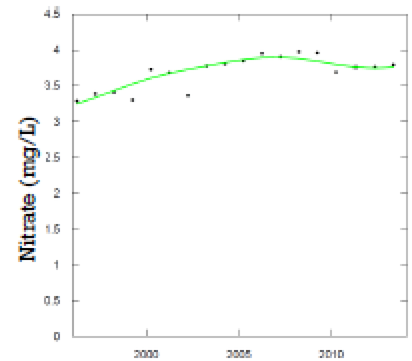




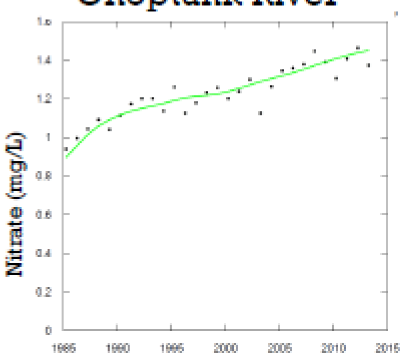
Susquehanna River



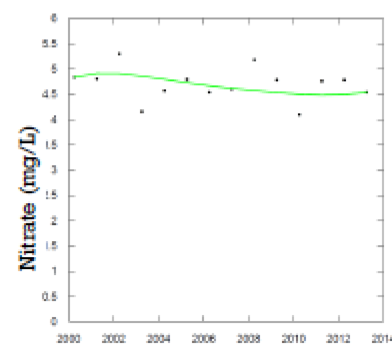
White Clay Creek



Choptank River



Nanticoke River



Long-Term Statistical Trend Analysis of Nitrate

Station	State	Trend
Red Clay Creek	DE	Degrading
White Clay Creek	DE	Degrading
Brandywine Creek	DE	Degrading
Christina River	DE	Improving
Susquehanna River	MD	Improving
Mispillion River	DE	Degrading
Nanticoke River	DE	Improving
Schuylkill River	PA	No Change
Wissahickon Creek	PA	Improving
Lehigh River	PA	Degrading
Big Elk Creek	PA	No Change
Choptank River	MD	Degrading

- Regional analysis of long-term trends shows a general increase in nitrate concentrations.

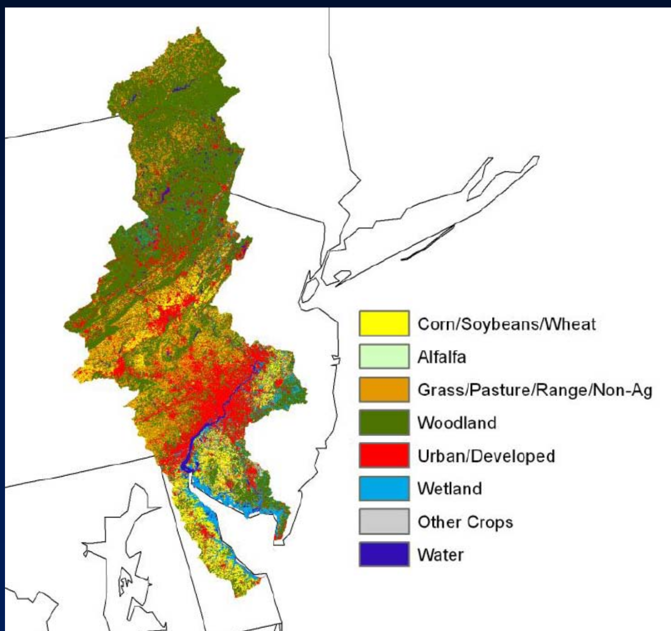
Note: Trend significance based on a 1% P-value using linear regression

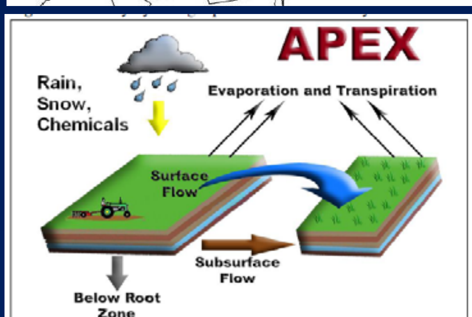
USDA NRCS
United States Department of Agriculture
Natural Resources Conservation Service

Conservation Effects Assessment Project (CEAP)

NOVEMBER 2014

Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Delaware River Basin





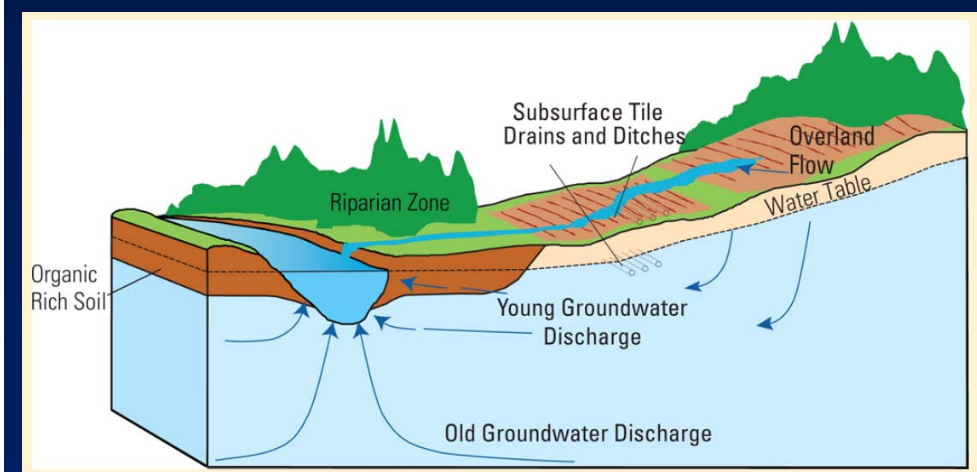
"... although farmers' use of conservation practices in the Delaware River Basin has made good progress toward reducing sediment, nutrient, and pesticide losses from farm fields, significant conservation treatment is still needed to reduce nonpoint agricultural sources of pollution."

While BMPs like riparian buffers are heavily promoted to improve water quality, there is evidence that such improvements could take many years to decades (e.g., Tesoriero et al., 2013).

Environmental Science & Technology
Article
pubs.acs.org/est

Vulnerability of Streams to Legacy Nitrate Sources

Anthony J. Tesoriero,*[,†] John H. Duff,[‡] David A. Saad,[§] Norman E. Spahr,[||] and David M. Wolock[⊥]



"Observations presented in this article establish that lag times on the order of decades occur in some streams and that legacy nitrate sources can result in increases in nitrate concentrations over time regardless of changes in current land use practices."

Hence there is an urgent need to examine other approaches that are fast-response, innovative and cost-effective, and that perhaps could be applied within a payment for ecosystem services scheme or nutrient trading.

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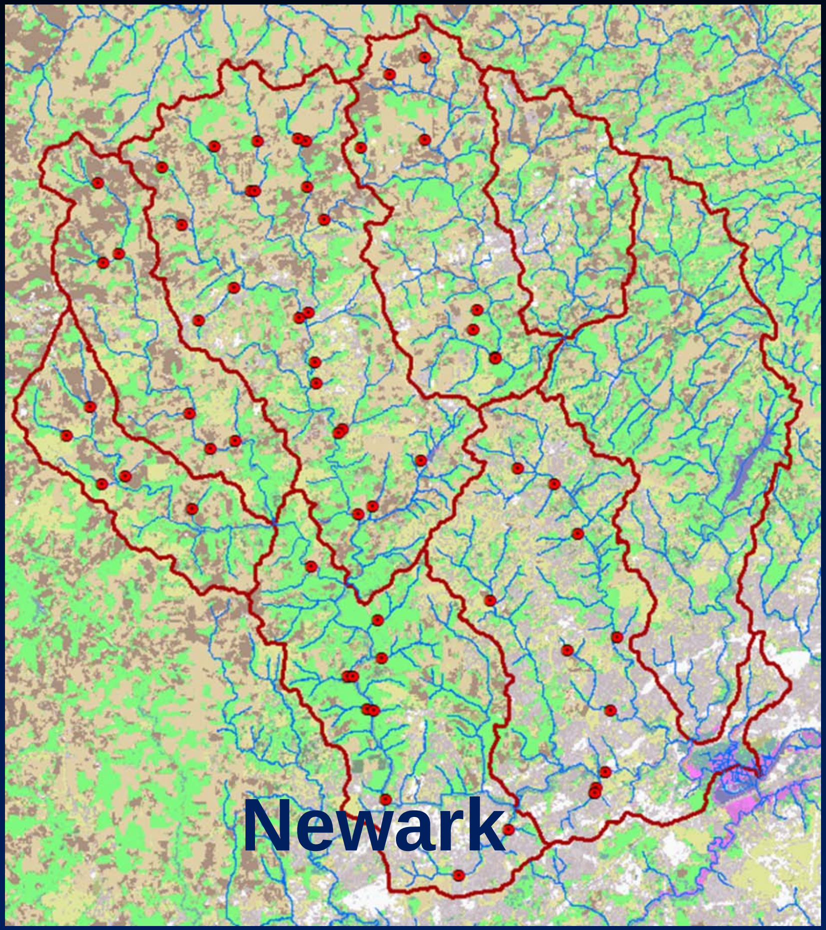
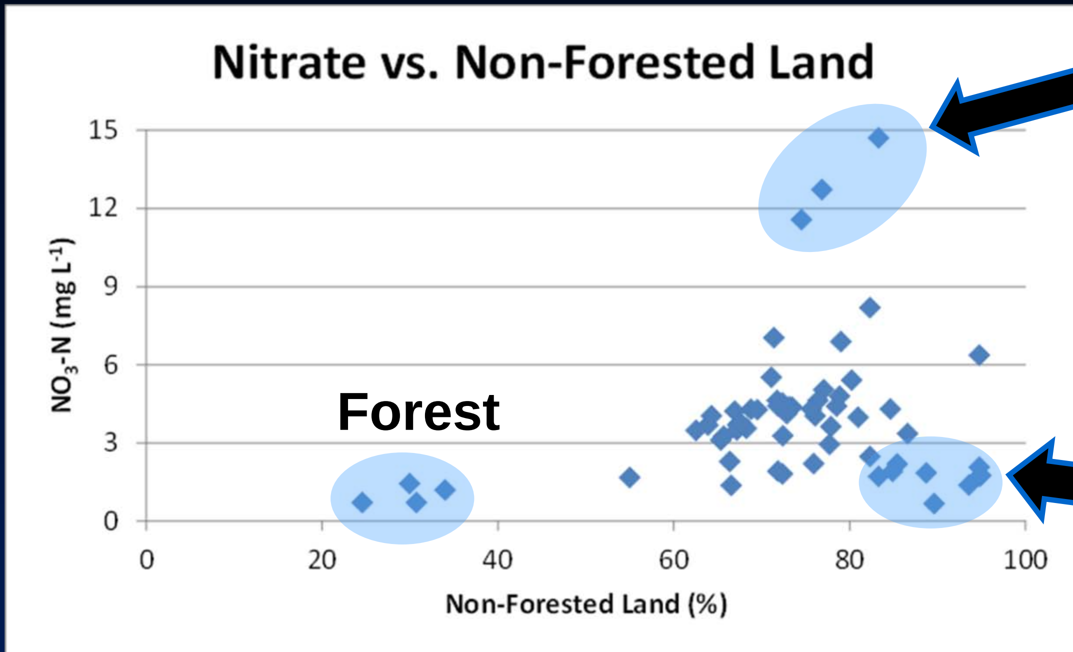
Snapshot Sampling



- ~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 excellent opportunities for targeted N reduction efforts.

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Check out the poster of Kelsey Moxey

Mushroom Farming

Step 1: Mushroom Substrate

Mixing ingredients (e.g., hay, horse bedding, poultry litter, cocoa shells, gypsum, water)

----2 to 3 weeks-----

Step 2: Growing Mushrooms

Pasteurization, spawning, casing, pinning

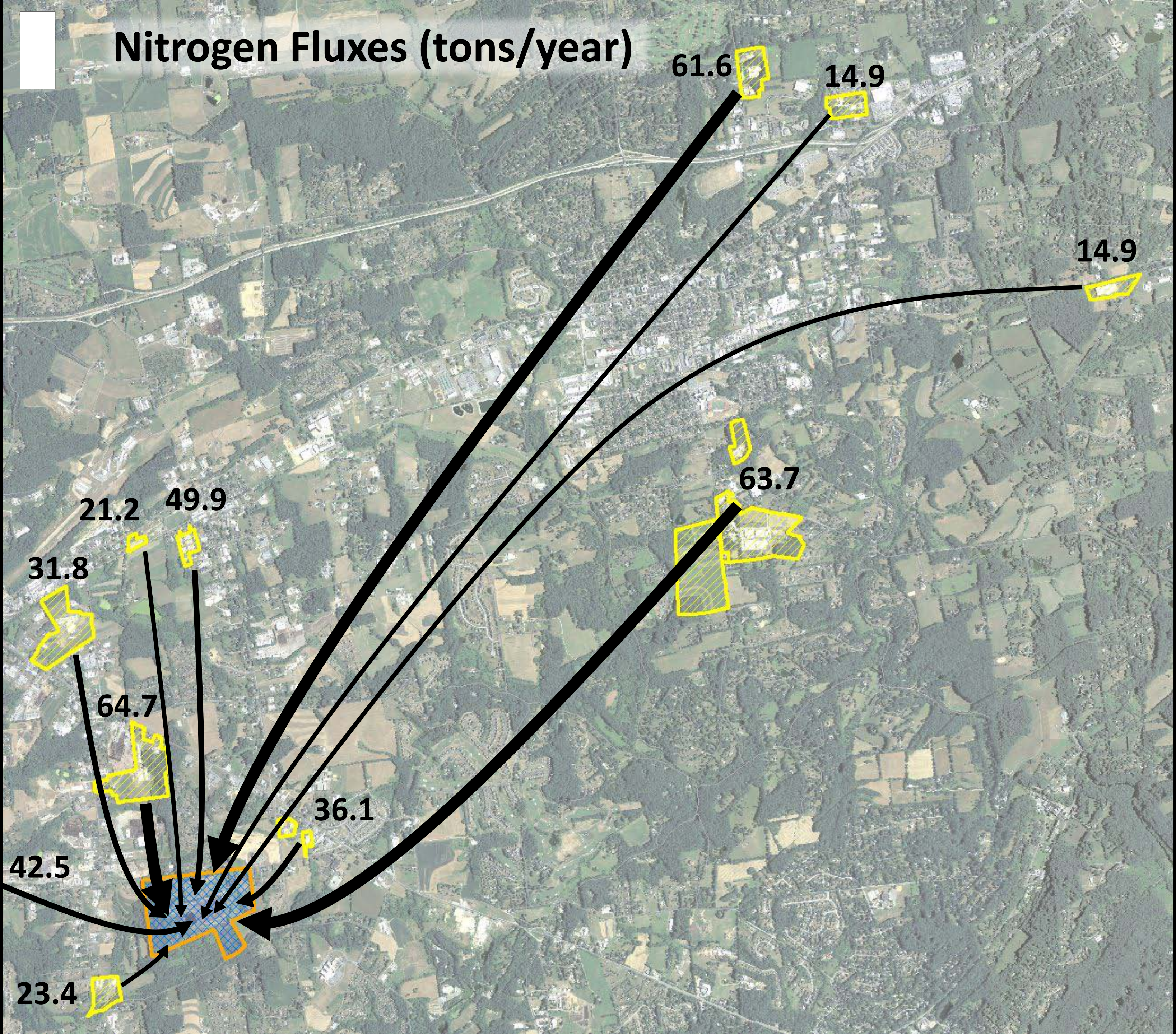
----7 to 8 weeks----

Step 3: Spent Substrate – Compost

Aging (passive & active)

----1 to 3 years----

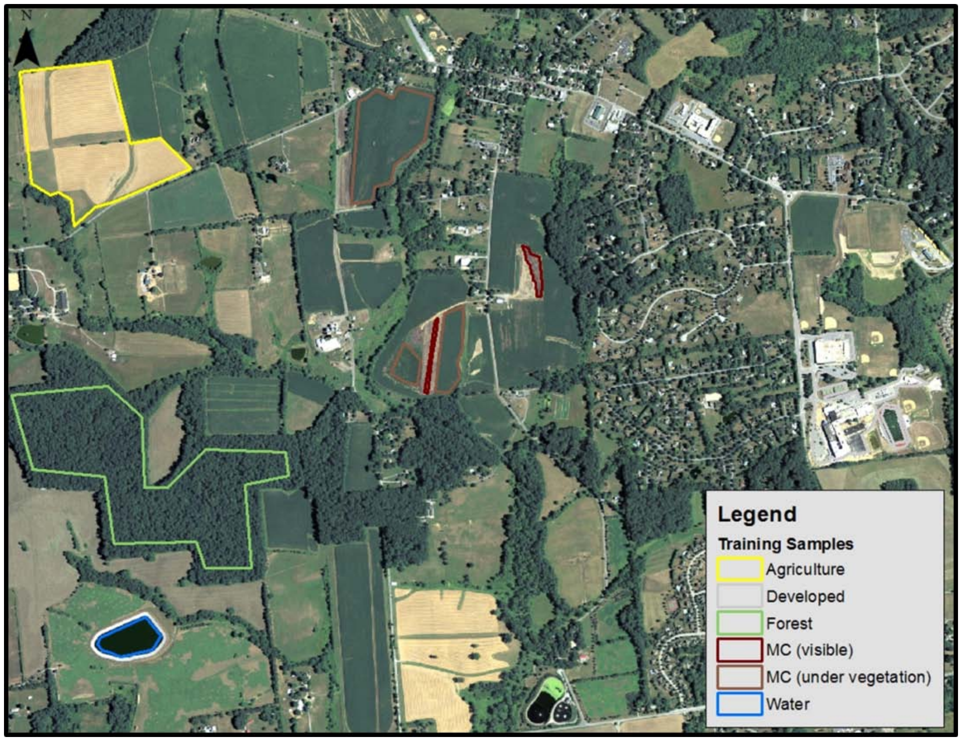
Nitrogen Fluxes (tons/year)



- In the past, mushroom compost has been over applied to fields in the region. Knowing the locations is important for identifying N hot spots and legacies, and to design N removal practices.

- Question: Can we use geospatial analysis to identify these locations of compost field applications?

Classification using remote sensing



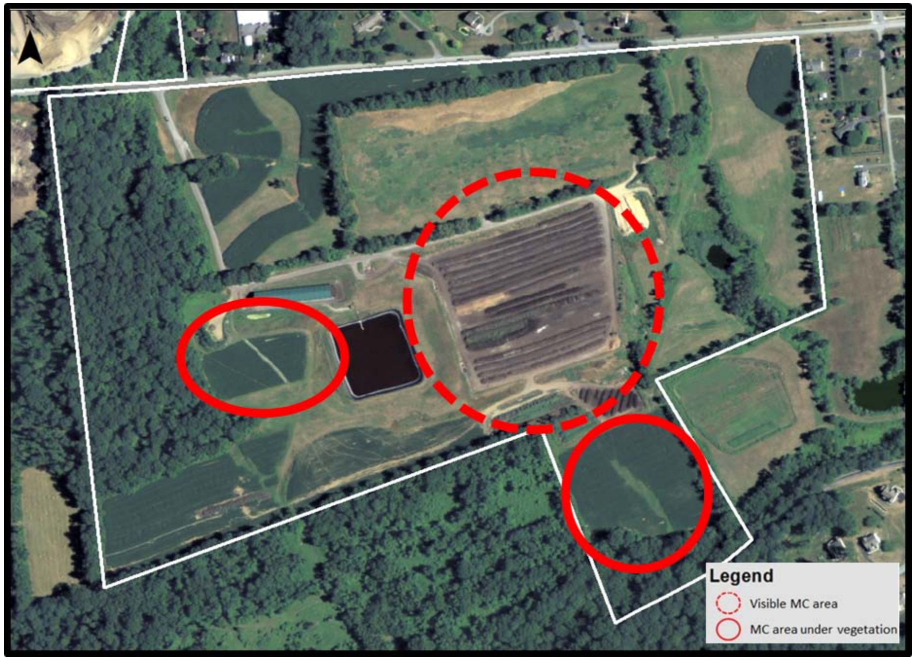
Training samples for mushroom compost delineation

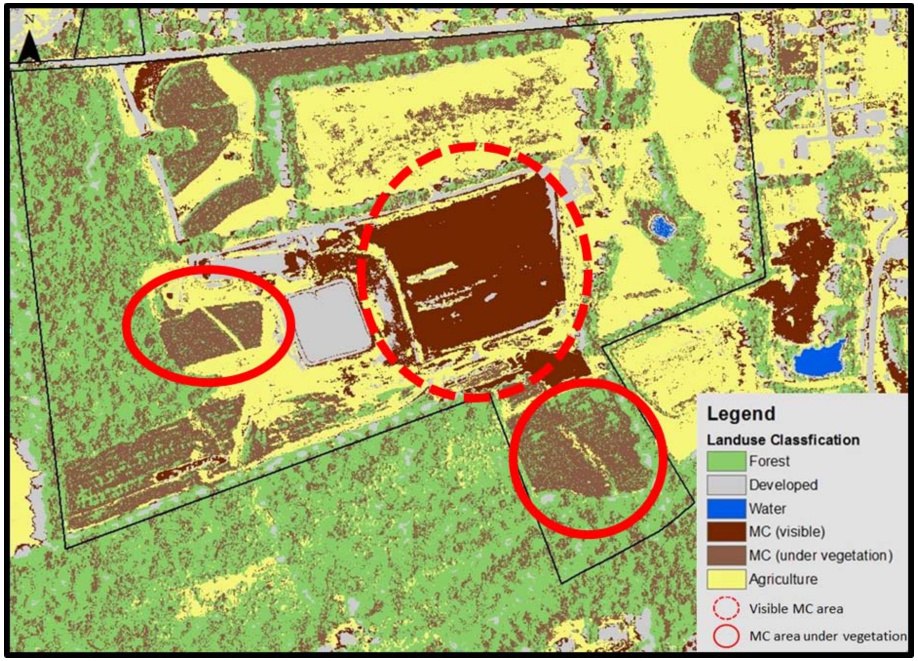
Data:
NAIP (National Agriculture Imagery Program), 1m resolution, 4 band, July 2010.

Spectral bands:
blue, green, red, near infrared

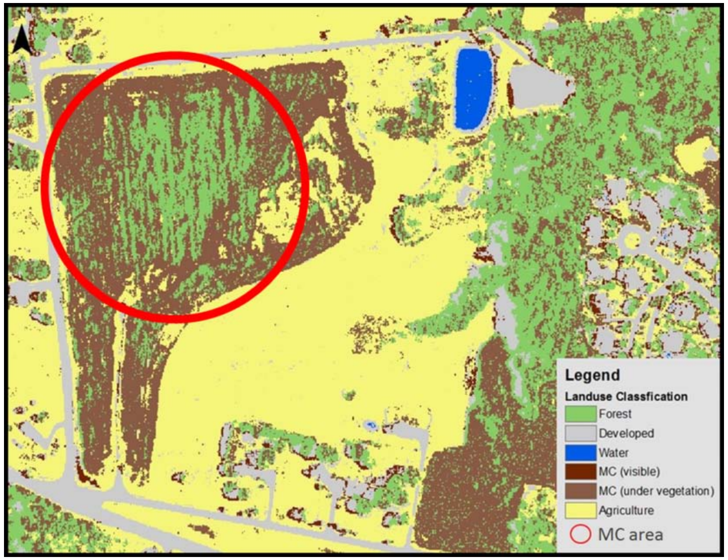
Classification method:
Maximum likelihood classification

<u>Known locations</u> are correctly classified

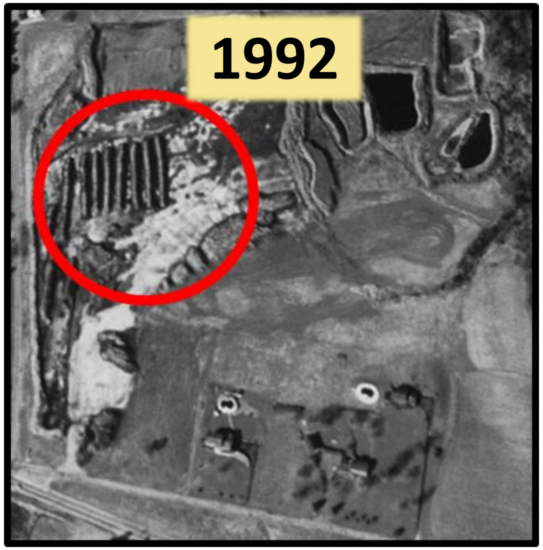


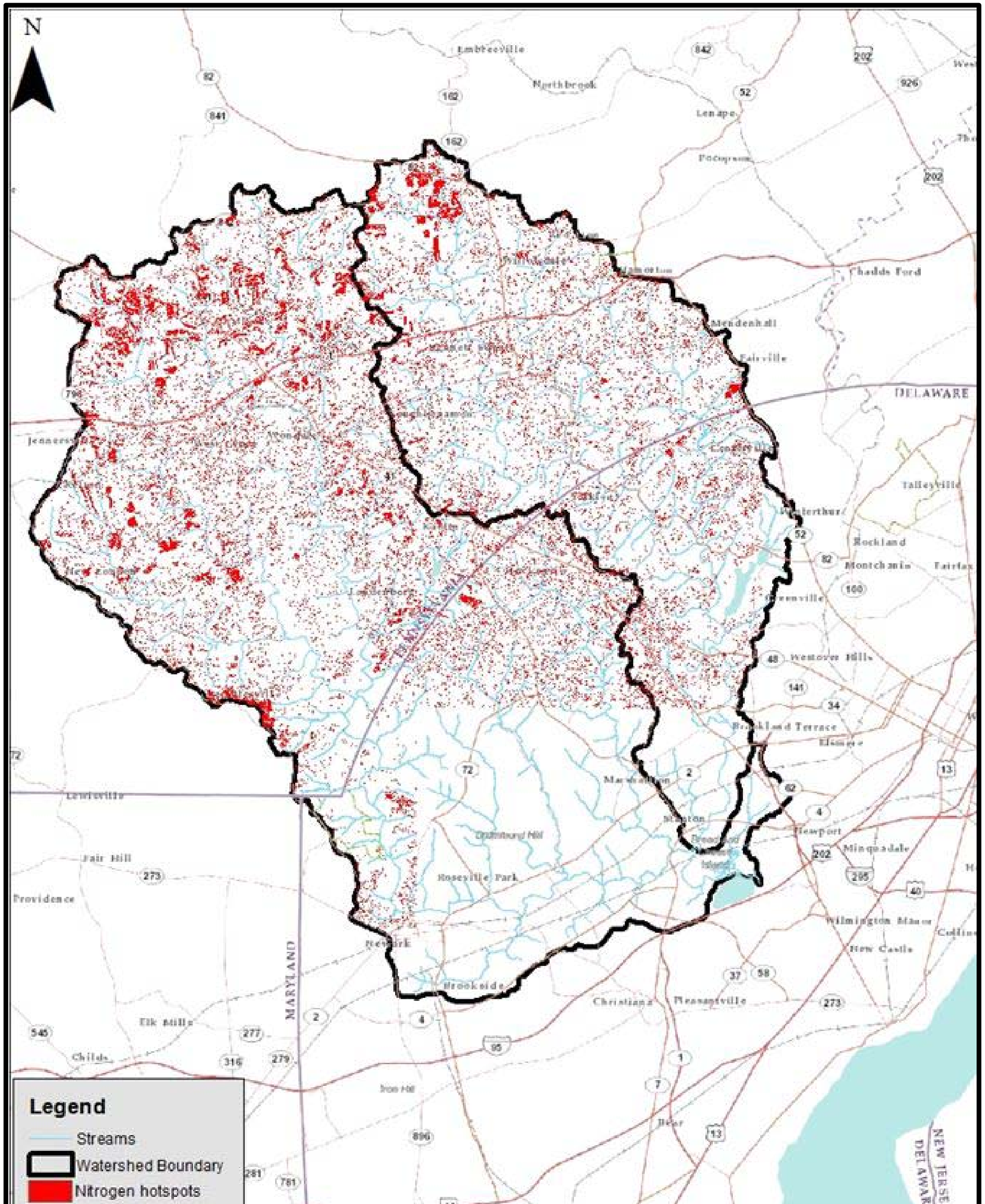


Also <u>unknown locations</u> are detected



Visual evidence

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Legend
Streams
Watershed Boundary
Nitrogen hotspots
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Mendenhall
Fairville
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Greenville
Westover Hills
Brookland Terrace
Elsmere
Newport
Minquadale
Wilmington Manor
New Castle
Christiana
Pleasantville
Newark
Brookside
Roseville Park
Marshallton
Stanton
Landenberg
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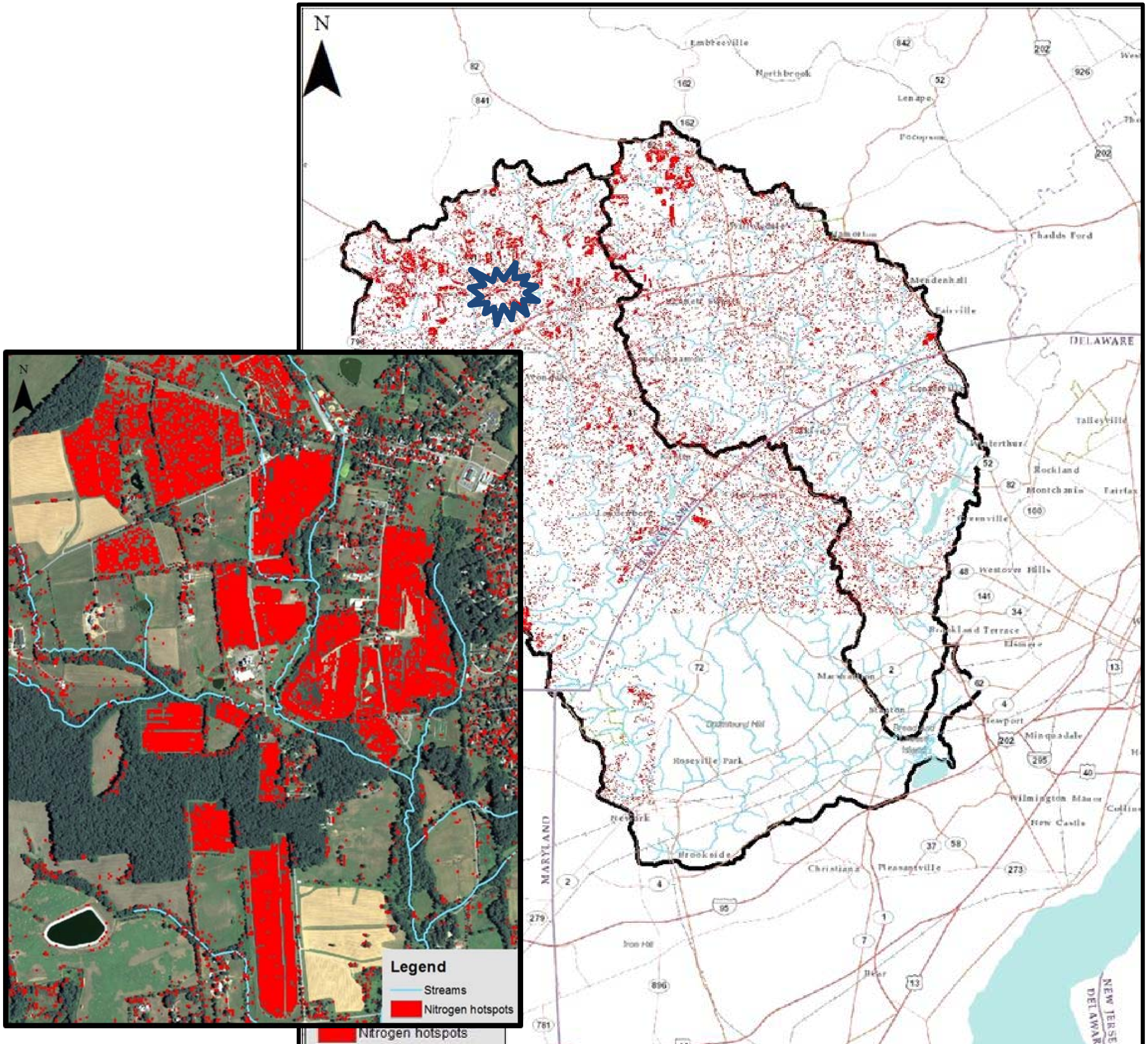
Providence
Elk Mills
Childs
Lewisville
Embreeville
Northbrook
Lenape
Iron Hill
Bear
NEW JERSEY
DELAWARE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Iron Hill
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Nitrogen hotspots
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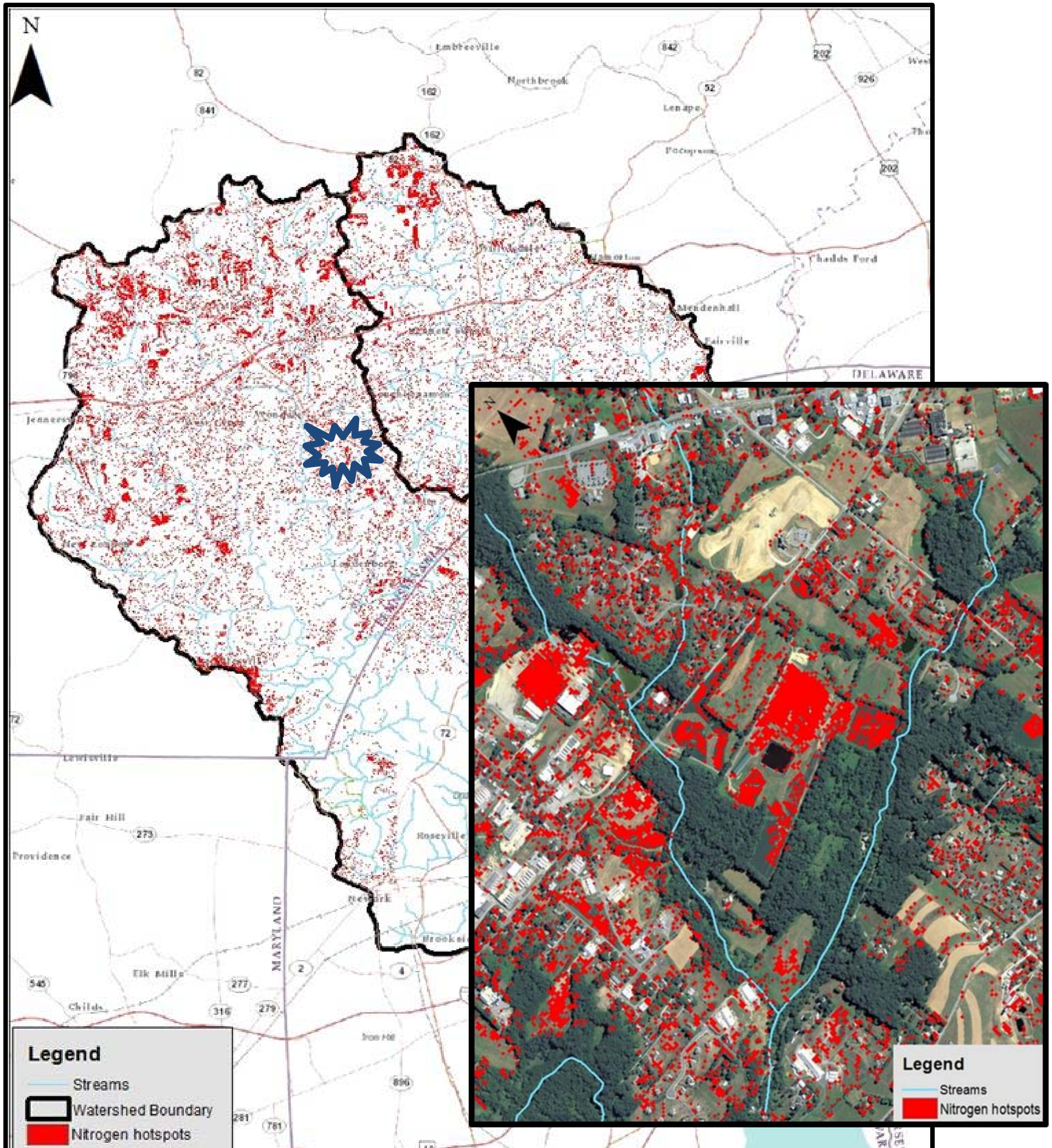
Streams
Nitrogen hotspots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Nitrogen hotspots

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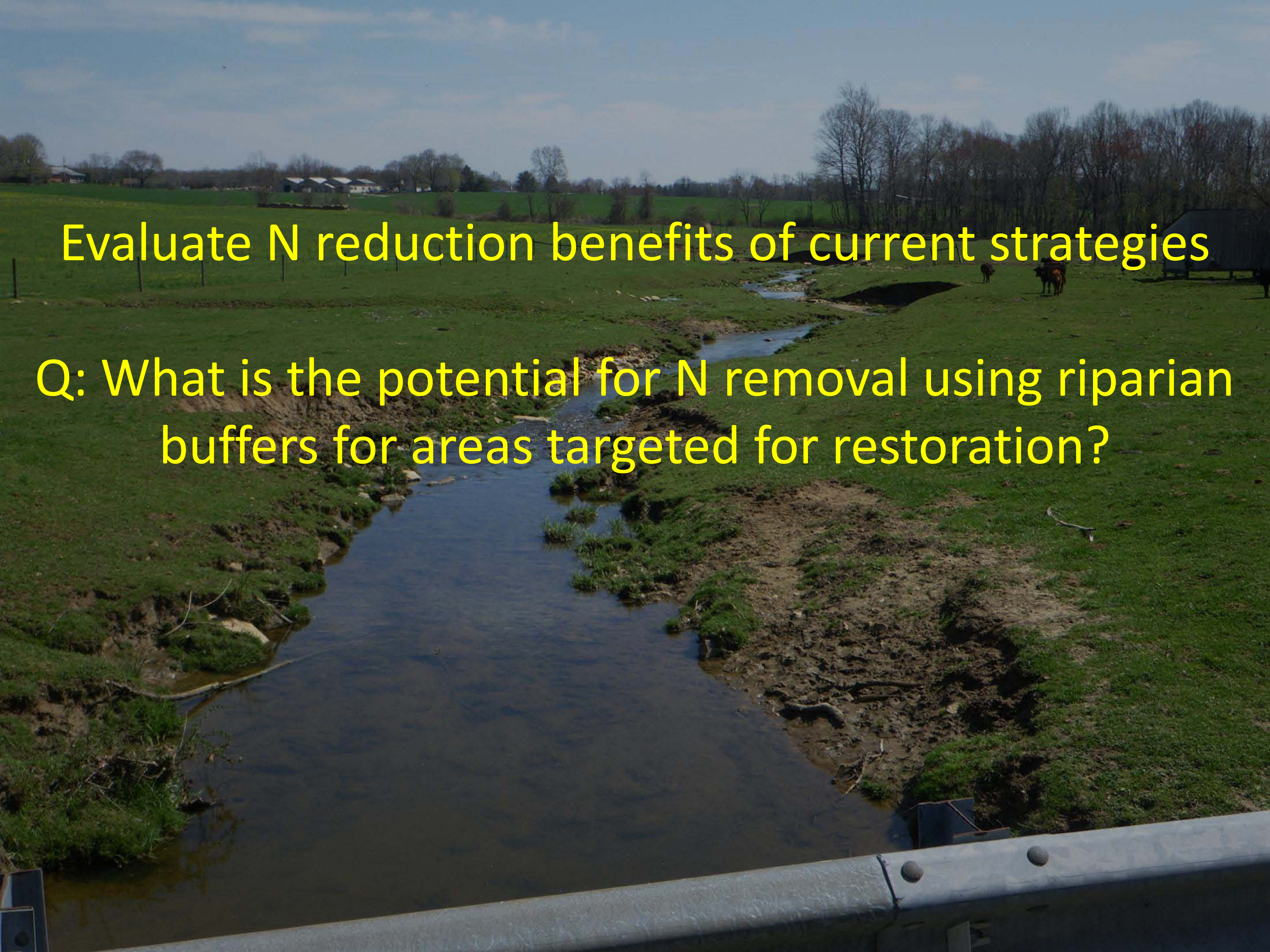
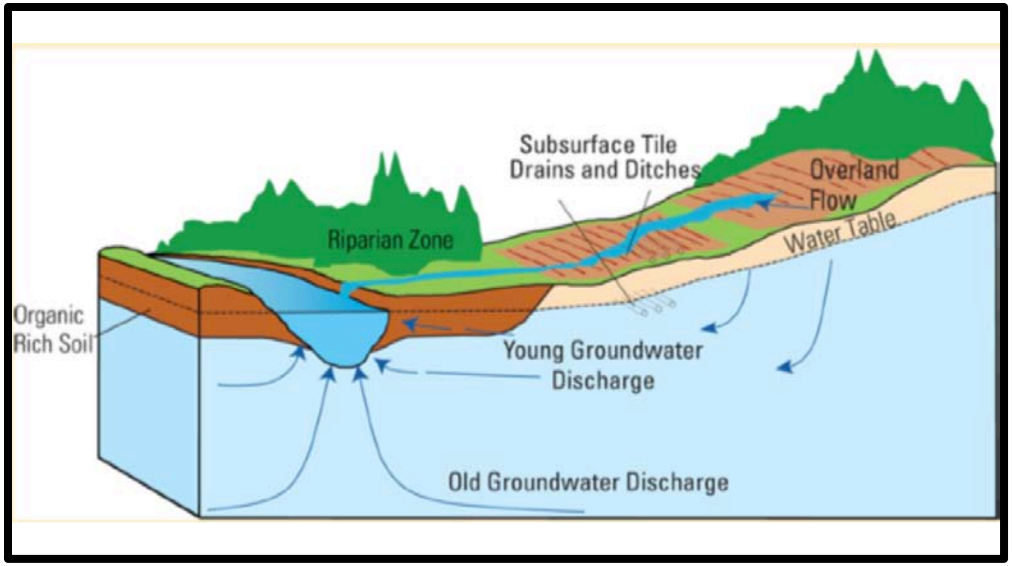
Check out the poster of Tom Santangelo


Evaluate N reduction benefits of current strategies
Q: What is the potential for N removal using riparian buffers for areas targeted for restoration?

Riparian Buffers

Functions of Riparian Buffers

- Reduce nutrient and sediment transport
- Contribute organic detritus to soil
- Provide terrestrial and aquatic habitat
- Cool stream temperature
- Bank stability
- Etc.



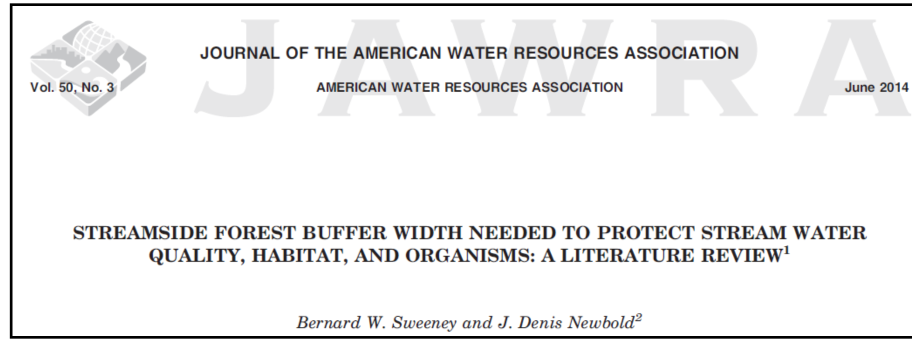
Tesoriero et al., 2012

Factors for nitrogen removal

- General characteristics (width, age, type)
- Nitrogen delivery from upland
- Hydrologic factors
  - Water flux
  - Residence time
  - Wetness
- Soil & geologic factors

Recent Findings

(Sweeney and Newbold, 2014)


JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

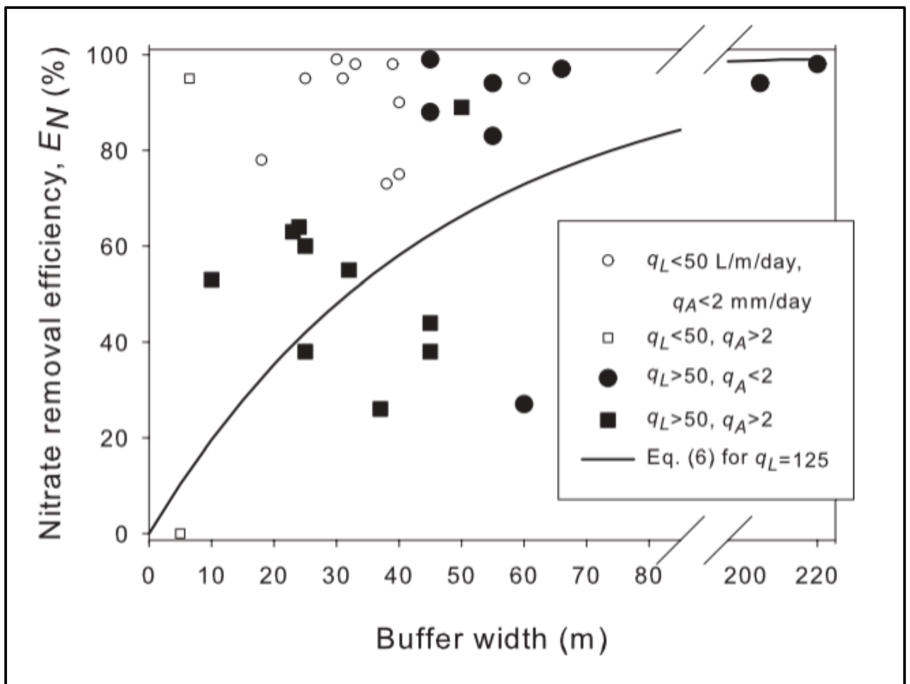
Vol. 50, No. 3 AMERICAN WATER RESOURCES ASSOCIATION June 2014

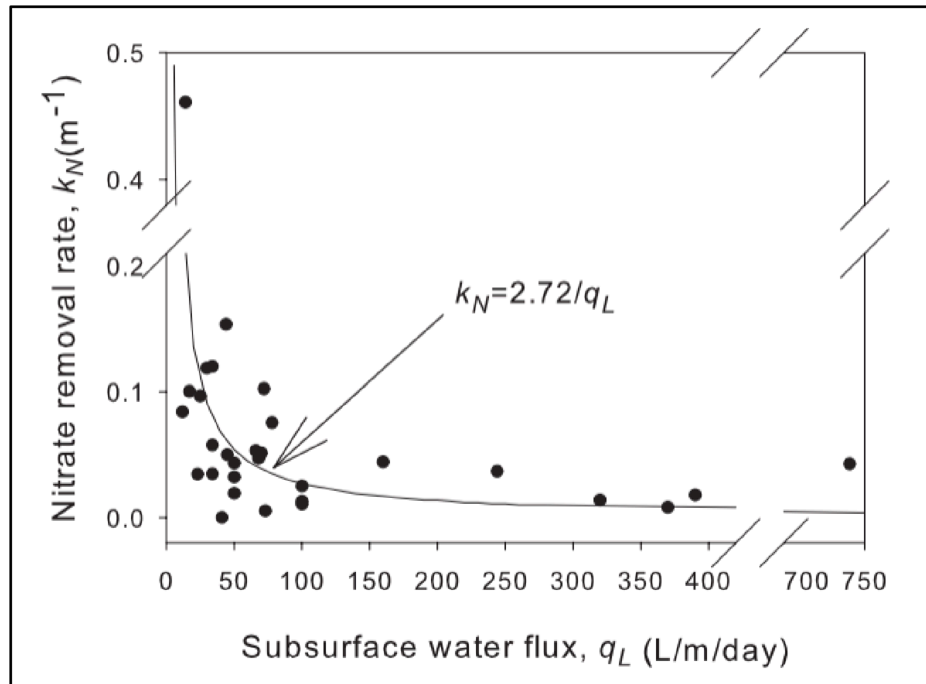
JAWRA

STREAMSIDE FOREST BUFFER WIDTH NEEDED TO PROTECT STREAM WATER QUALITY, HABITAT, AND ORGANISMS: A LITERATURE REVIEW[1]

Bernard W. Sweeney and J. Denis Newbold[2]

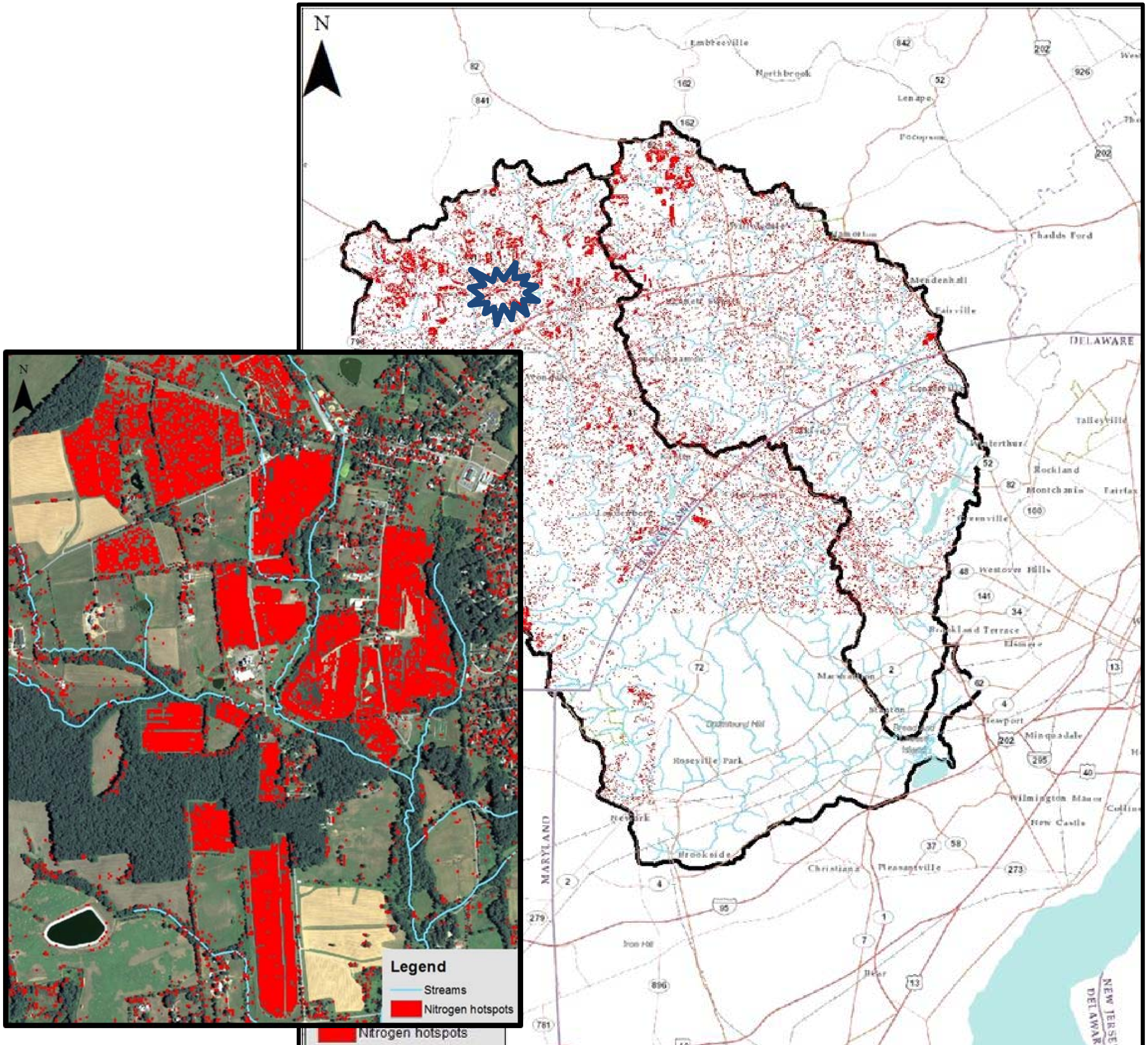
An extensive literature review of empirical studies shows that lateral water flux and buffer width are key factors in buffer effectiveness.





- While the factors controlling riparian N removal are generally well know, their spatial application for management purposes is not yet sufficiently developed.

- Building on the empirical Sweeney & Newbold (2014) equations we are developing a spatially explicit GIS model that can be used for prioritizing buffer locations and widths, as to meet desired reductions in N loading.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Montchanin
Fairfax
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Newark
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Christiana
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MARYLAND
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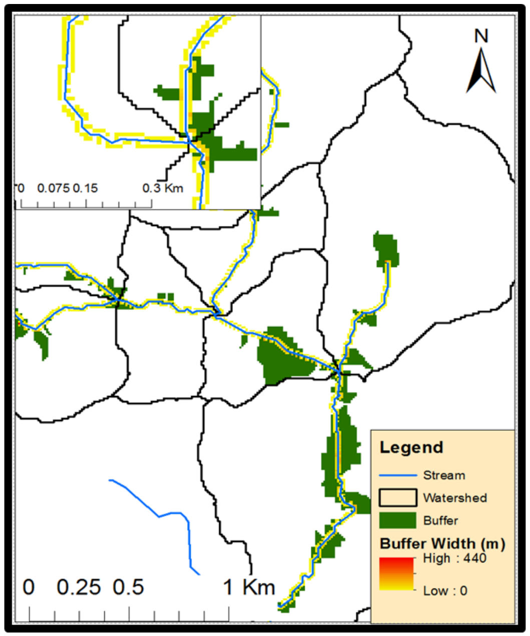
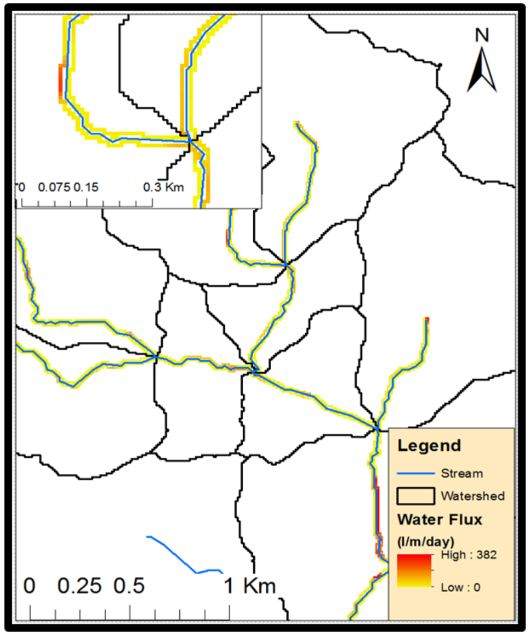
Nitrogen hotspots
Nitrogen hotspots

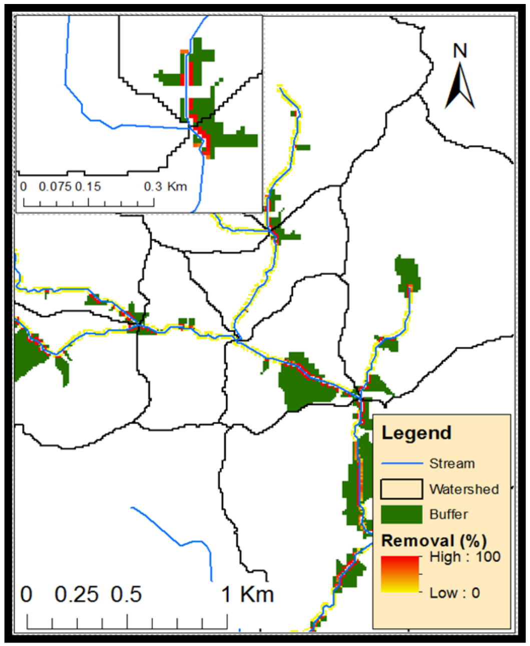
Results for existing buffer widths



a. Buffer Width (m)

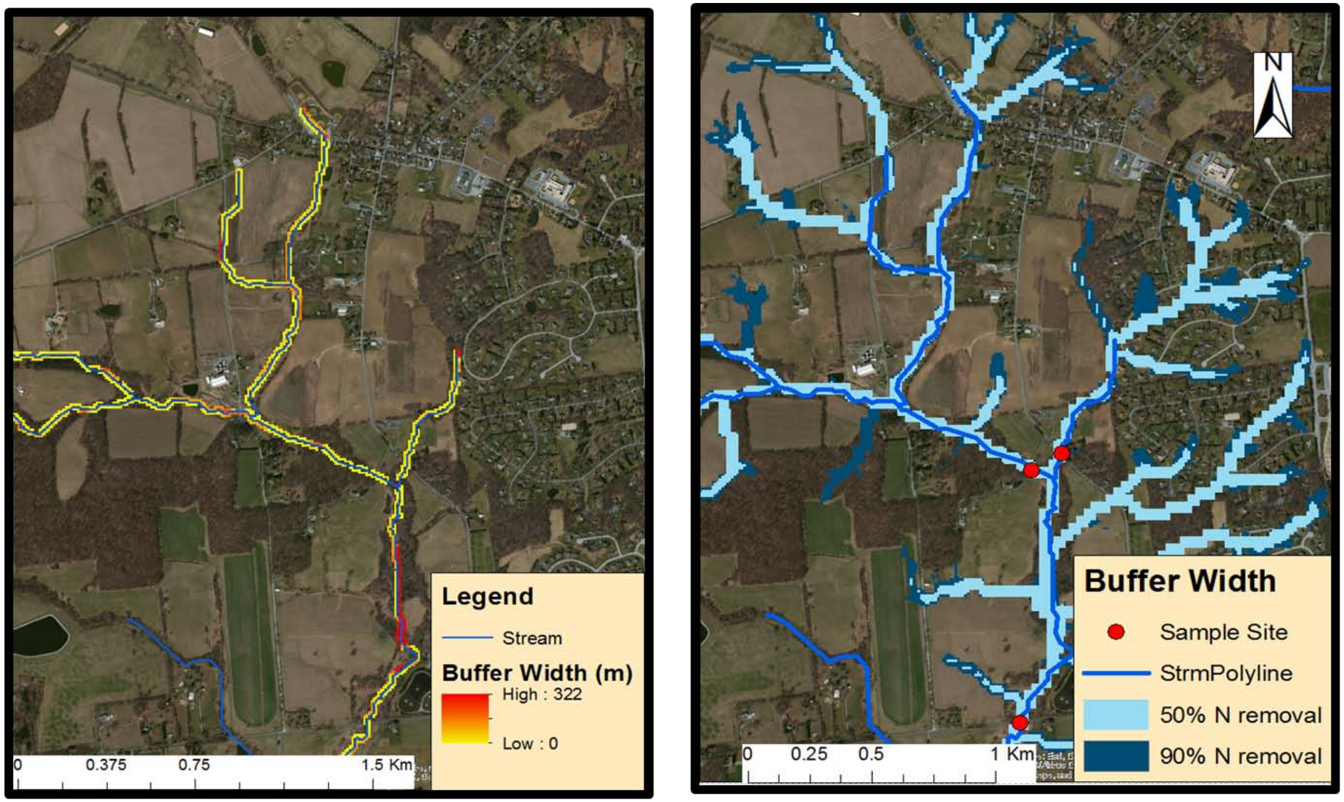


b. Water flux (l/m/day)



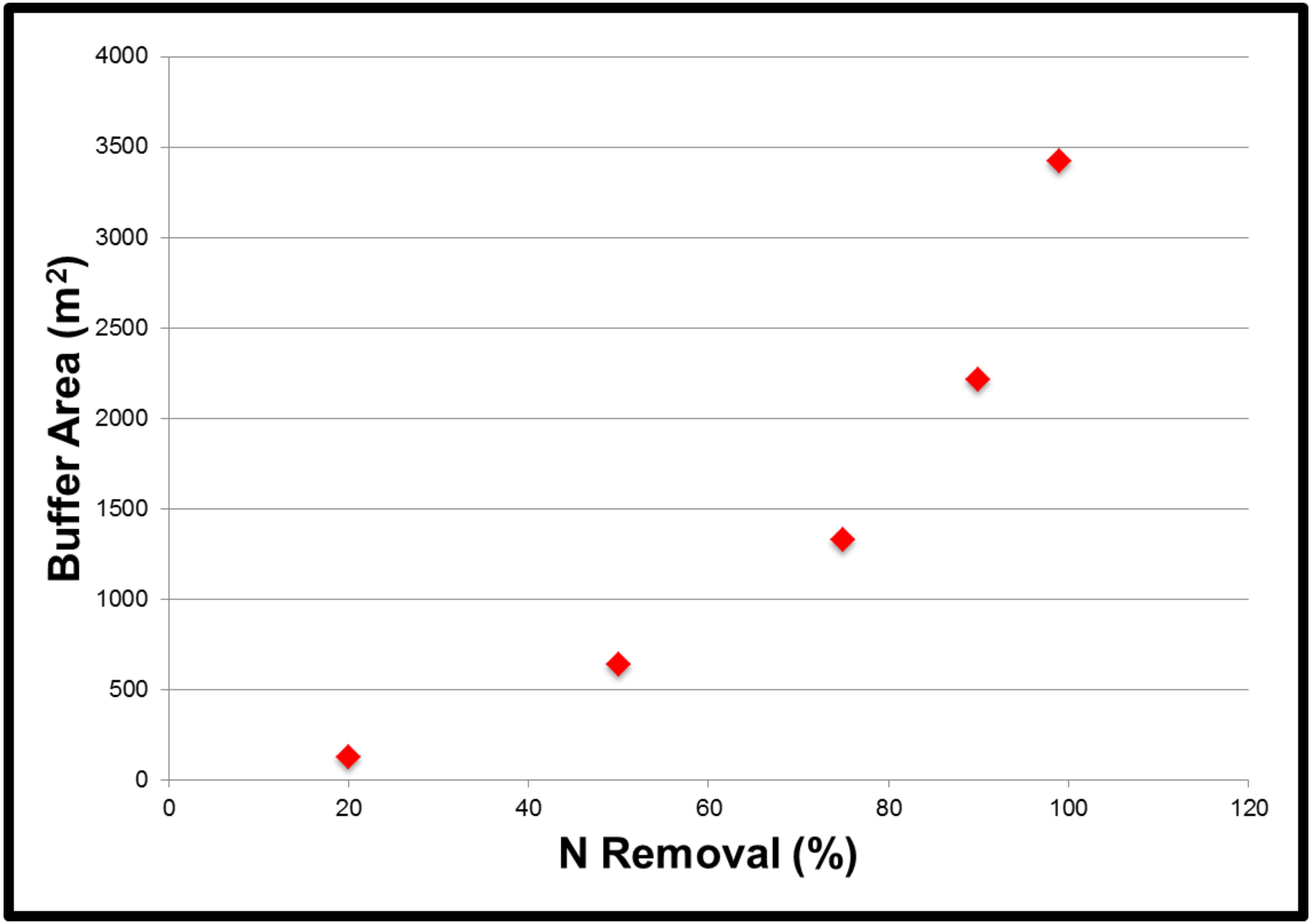
c. Removal (%)

Buffer widths for 90% N removal



a. Buffer Width (m)   b. Mapped buffers

Buffer widths for 90% N removal



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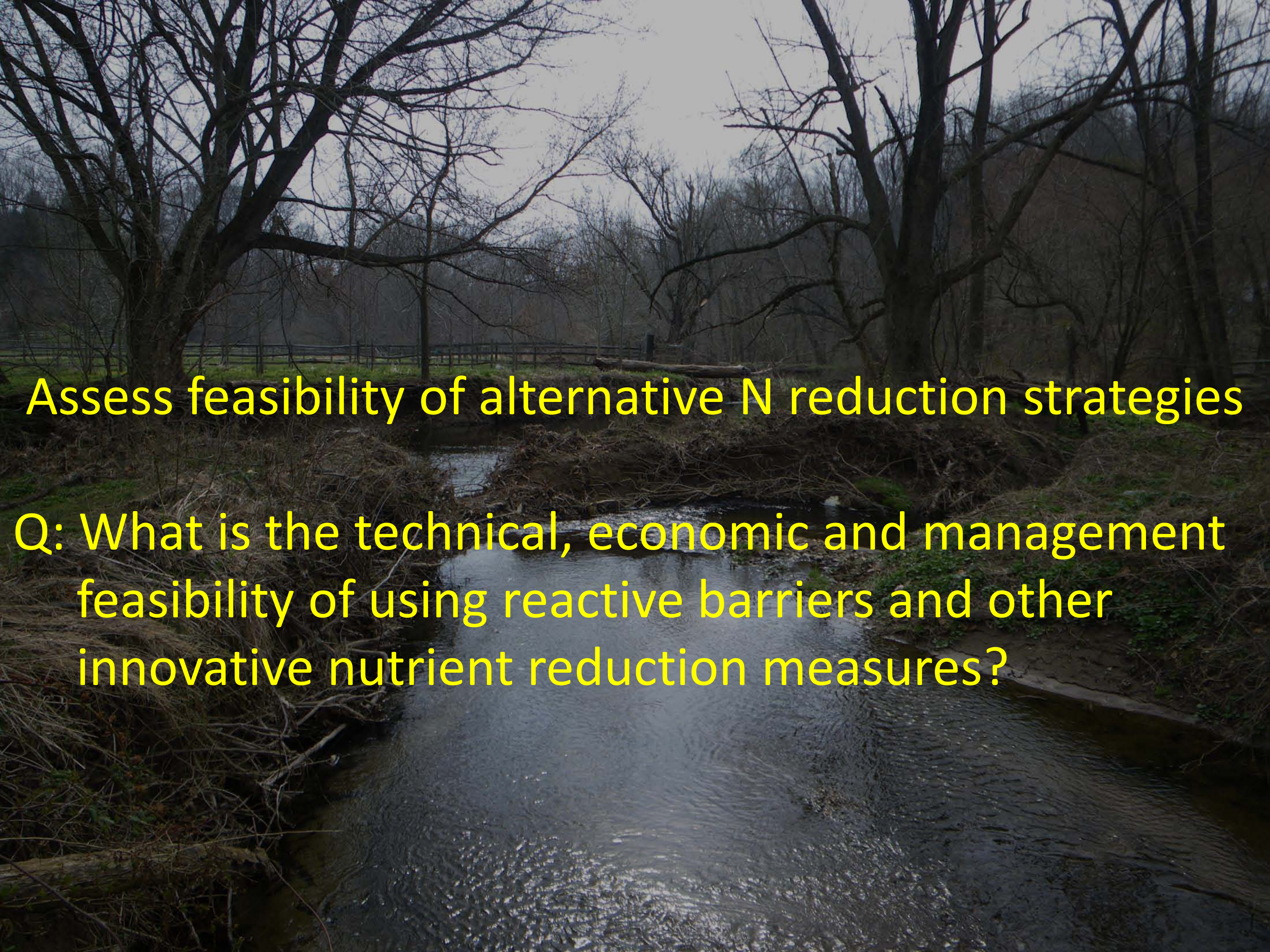


Assess feasibility of alternative N reduction strategies

Q: What is the technical, economic and management feasibility of using reactive barriers and other innovative nutrient reduction measures?

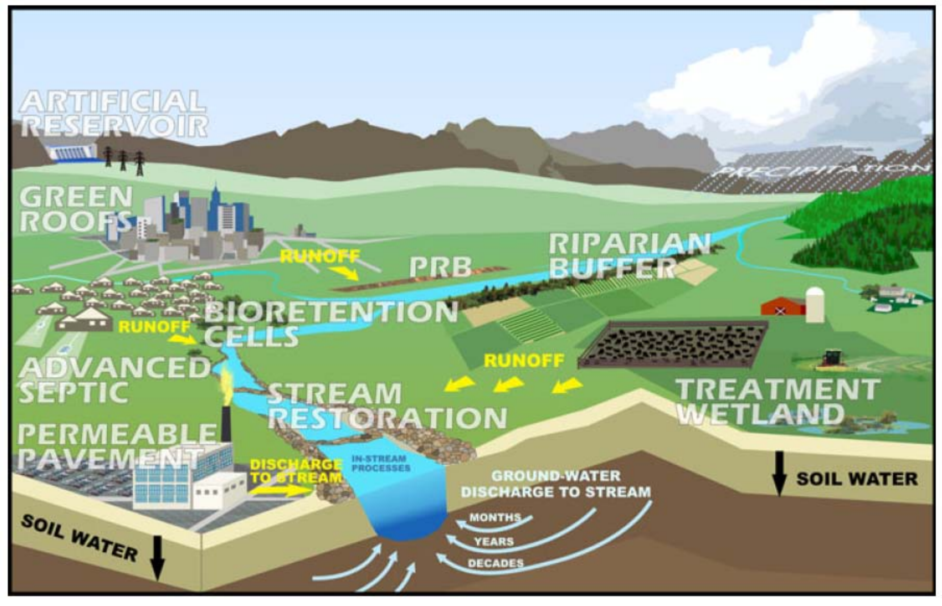
- Because of uncertainty in BMP effectiveness and associated lag times, there is a need for N reduction approaches that are innovative, fast-response, and cost-effective.

- Innovative both in technical aspects (environmental science and engineering) and in management aspects (policy).

Environmental Management (2013) 51:392–413
DOI 10.1007/s00267-012-9970-y

Ecological Engineering Practices for the Reduction of Excess Nitrogen in Human-Influenced Landscapes: A Guide for Watershed Managers

Elodie Passeport · Philippe Vidon · Kenneth J. Forshay ·
Lora Harris · Sujay S. Kaushal · Dorothy Q. Kellogg ·
Julia Lazar · Paul Mayer · Emilie K. Stander



"There remains a critical need for systematic empirical studies documenting N-removal efficiency among EEPs and potential environmental and economic tradeoffs..."

Enhancing N Removal – Innovative Approach Technical Aspects

Permeable reactive barriers, "denitrification walls"

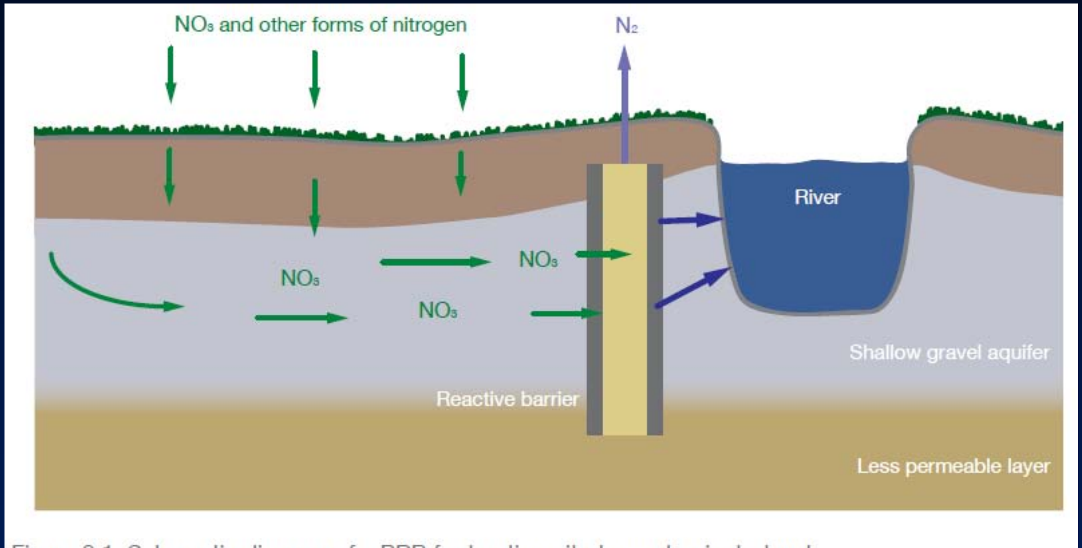
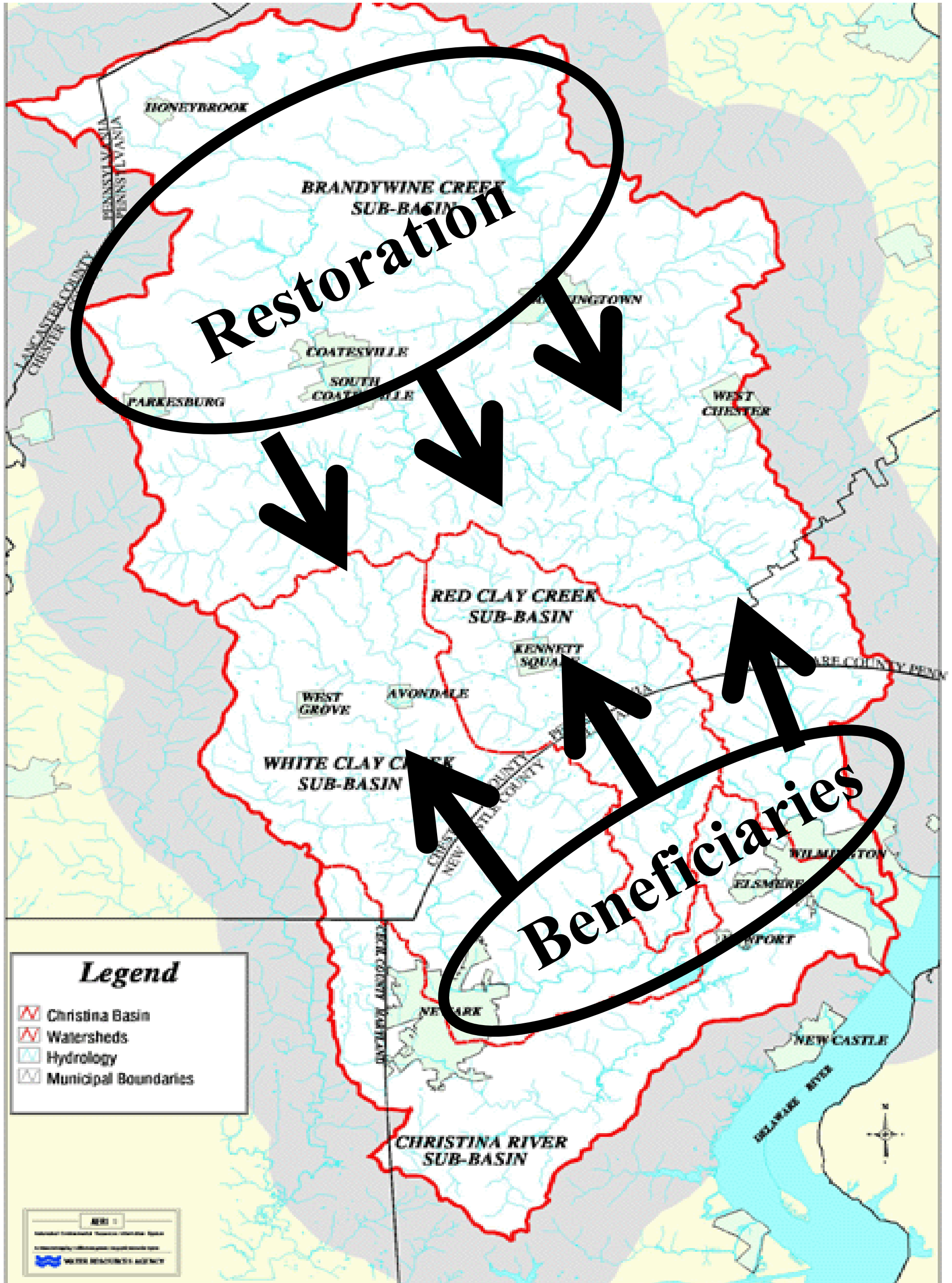


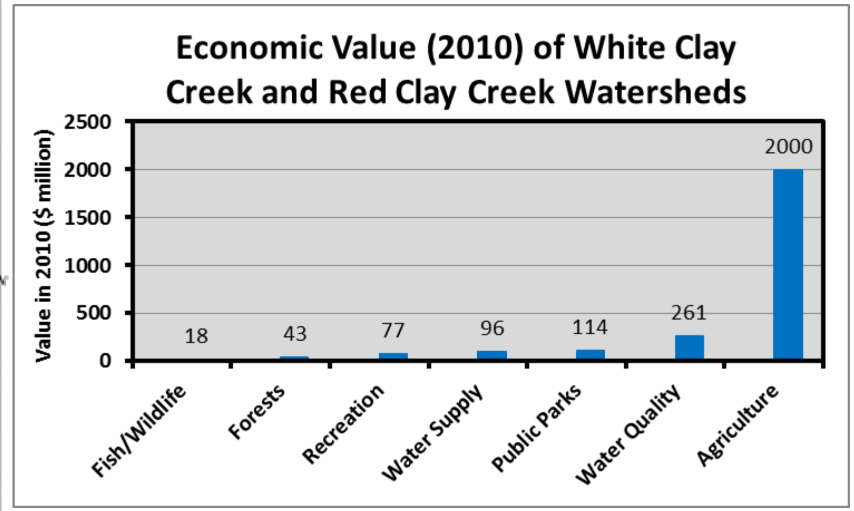
Figure 2.1: Schematic diagram of a PRB for treating nitrate-contaminated water.

(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

Innovative Approach Policy Aspects





(Source: Kauffman and Jones, 2014)

Next Steps

- Geospatial and process-based modeling (riparian buffers; remote sensing of N hotspots).
- WQ monitoring (continuous sensing; baseflow and stormflow).
- N source tracking (stable isotopes).
- Preliminary design of innovative practices.
- Economic analysis (cost and benefits; funding structure).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