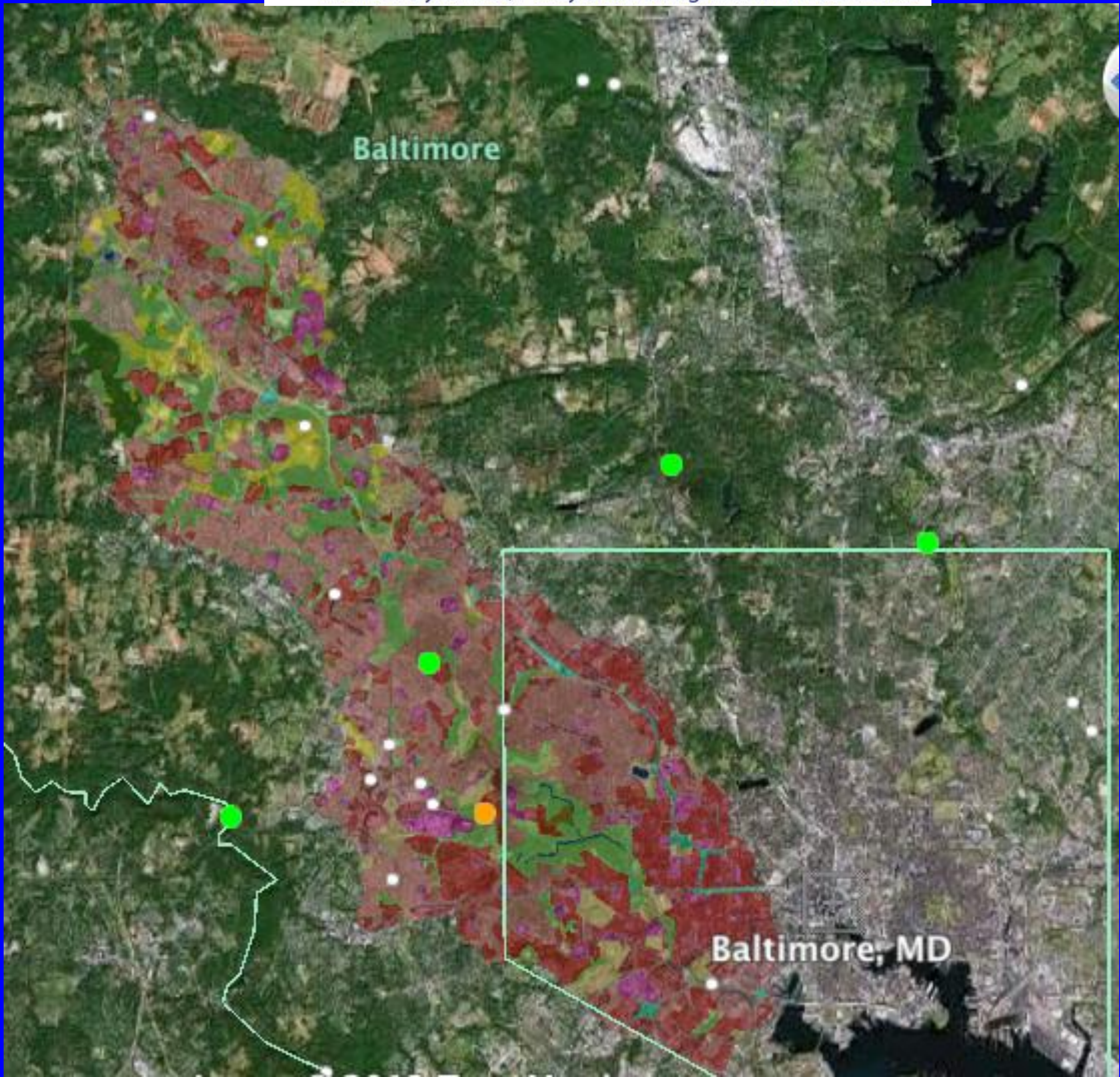
Sources and Cycling of Water, Carbon and Nutrients Urban Watersheds

Sustainable Water Resources
Complex Challenges, Integrated Solutions
Nutrient Dynamics, Policy and Management in Watersheds



Larry Band
University of North Carolina

Baltimore LTER

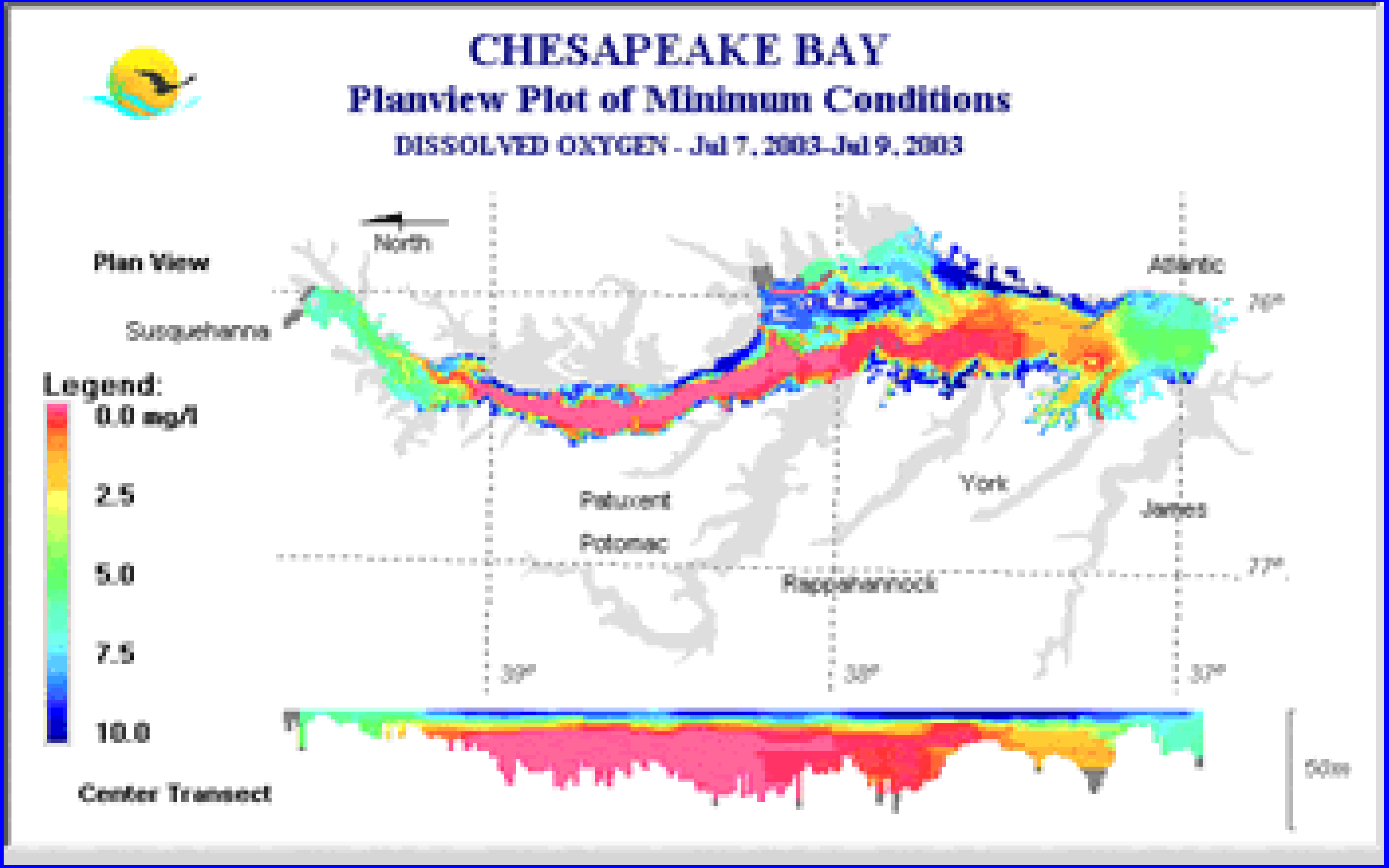
Baltimore LTER students and collaborators

- Jon Duncan, Monica Lipscomb, Catherine Shields, Tamara Mittman – UNC
- Peter Groffman, Steward Pickett – Cary Inst Ecosystem Studies
- Sujay Kaushal - UMD
- Claire Welty, Andy Miller – UMBC
- Rich Pouyat, Morgan Grove – USFS
- Naomi Tague – UCSB

The Three Central Questions of the Baltimore Ecosystem Study:

- ***FLUXES...***
  - ***What are the fluxes of energy and matter in urban ecosystems, and how do they change over the long term?***
- ***RELATIONSHIPS...***
  - **How does the spatial structure of ecological, physical, and socio-economic factors in the metropolis affect ecosystem function?**
- ***LINKAGES...***
  - ***How can urban residents develop and use an understanding of the metropolis as an ecological system to improve the quality of their environment and their daily lives?***

Hydroclimate impacts on water quality



Chesapeake Bay Foundation (www.cbf.org)

- 2003 dead zone one of the most severe on record
- Extreme drought followed by extreme precipitation
  - Flushing effect

Nitrogen export into the Chesapeake Bay
Baltimore LTER

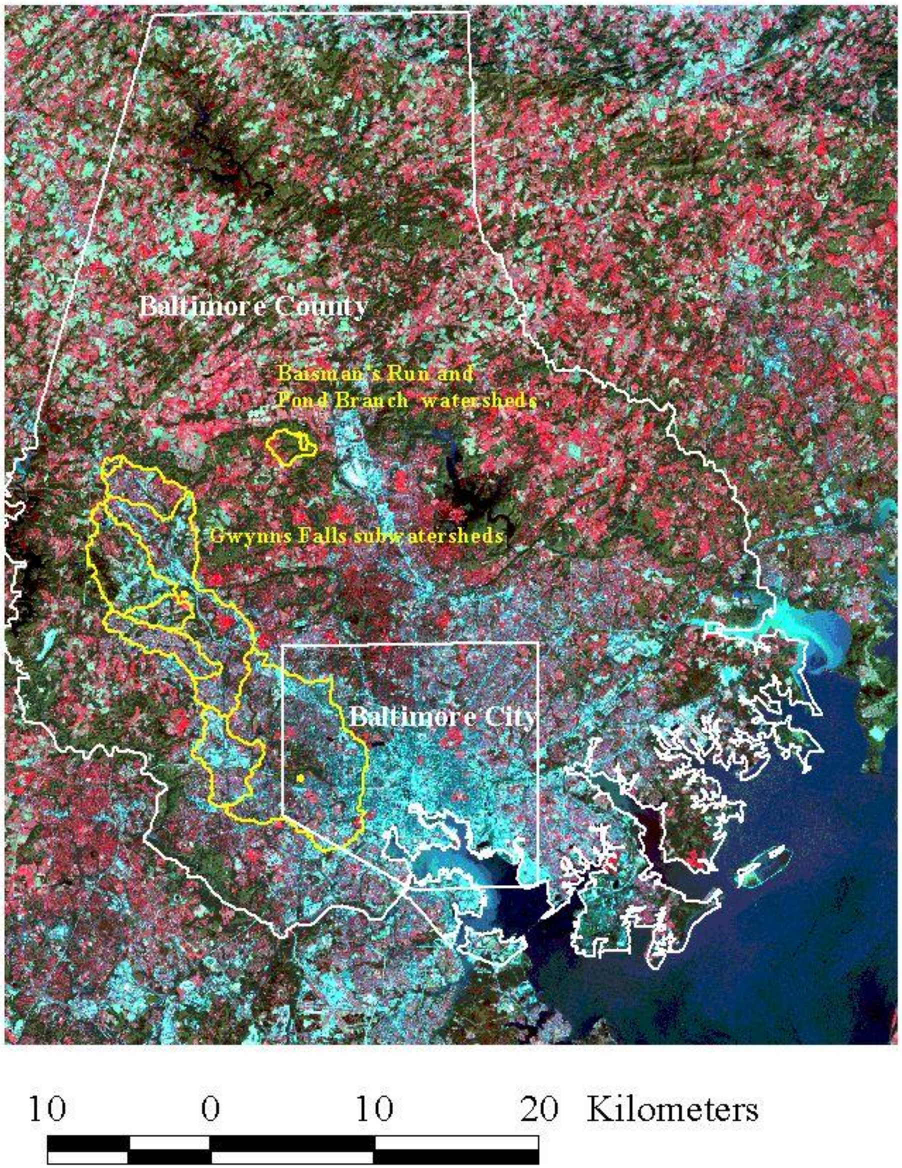
- The Chesapeake Bay has significant eutrophication problems: low water quality, algae blooms, anoxia, fishery declines, …

- Nitrogen is a limiting nutrient: consortium of five states, DC, federal agencies collaborating on reducing N, P, sediment loads across different sectors, land uses, locations
  - urban sources N ~30-40%

- Baltimore City/County under consent decree to significantly reduce N export including point and non-point in urban, suburban, rural catchments

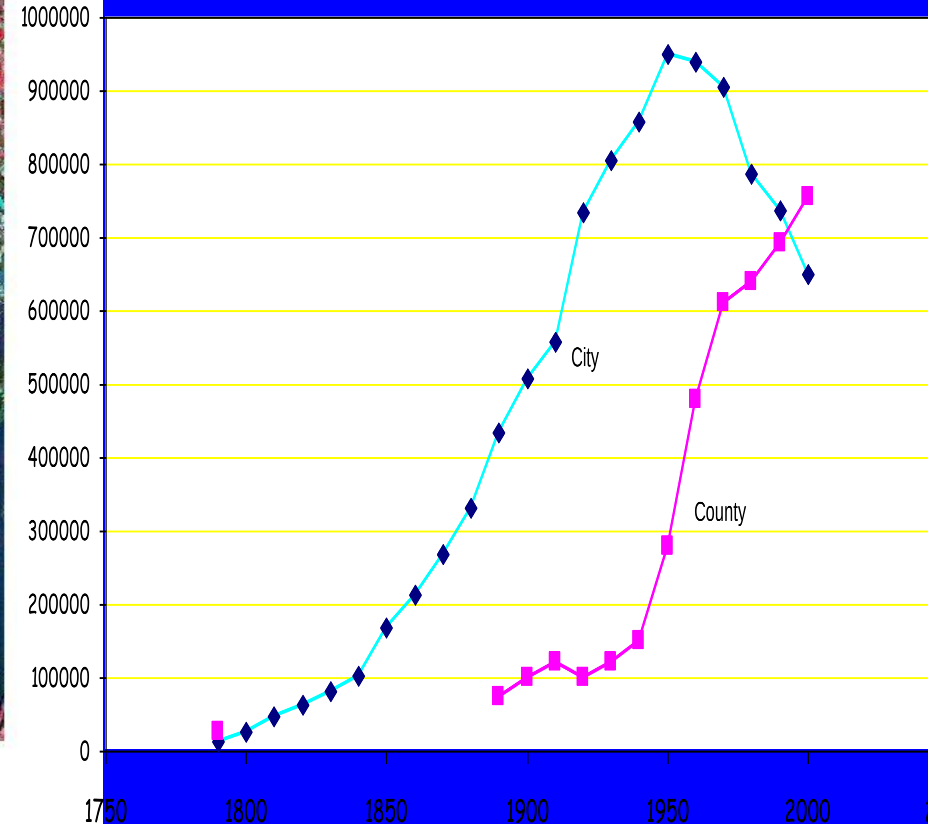
Need to prioritize restoration efforts to maximize N reduction, balanced with economic/social equity

Location map for the BES watersheds, Gwynns Falls and Baisman's Run

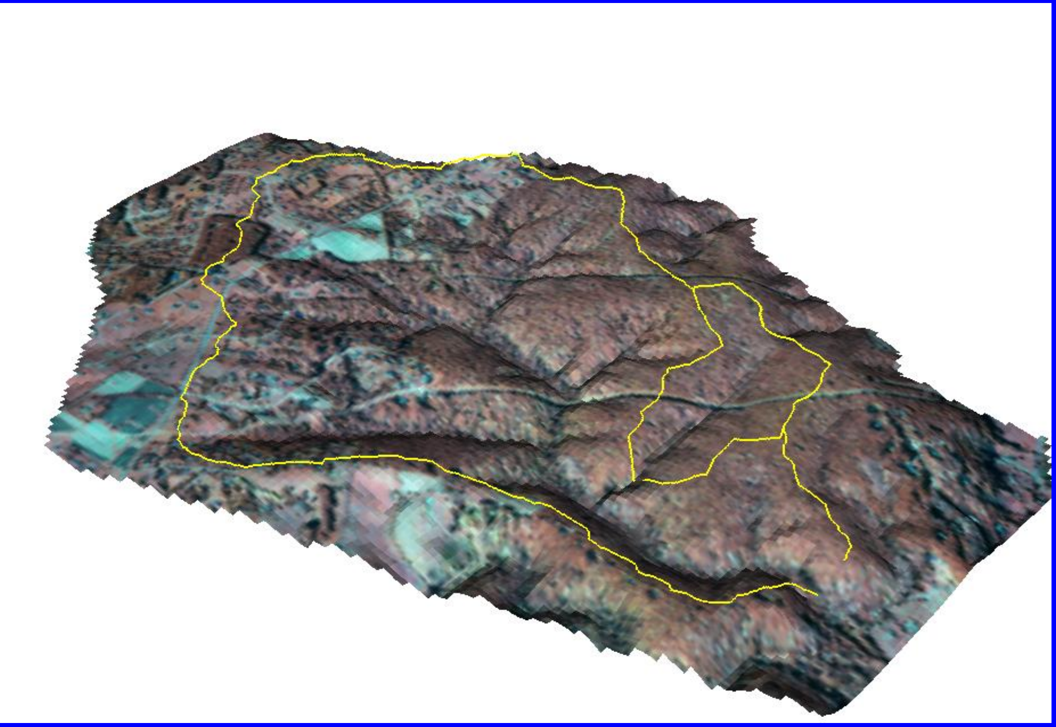


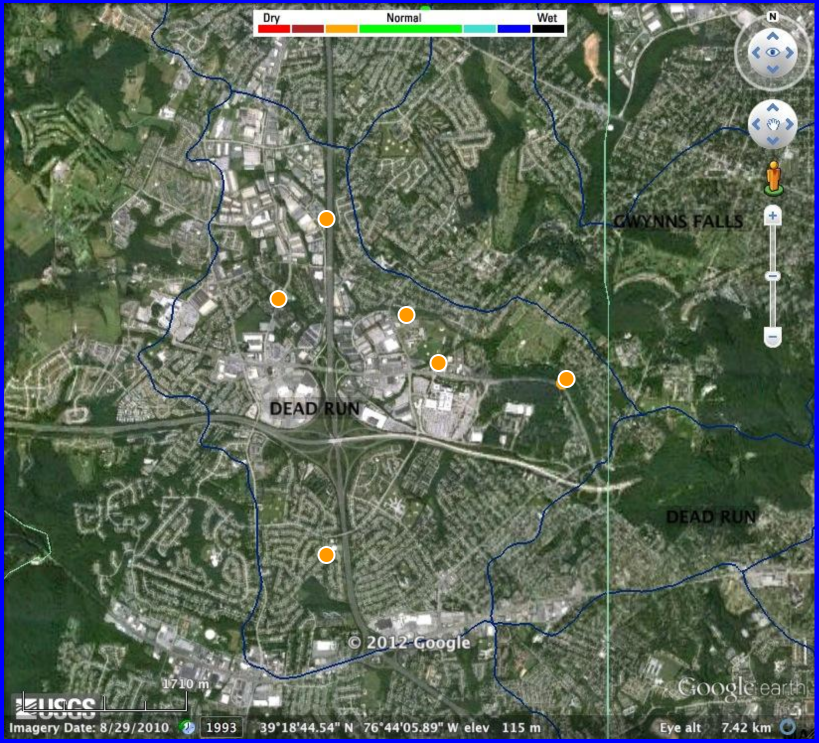
Population trends in Baltimore

Population in Baltimore City and County, 1790 to 2000



Nested, gauged catchments: regrowth forest, agricultural, dense urban



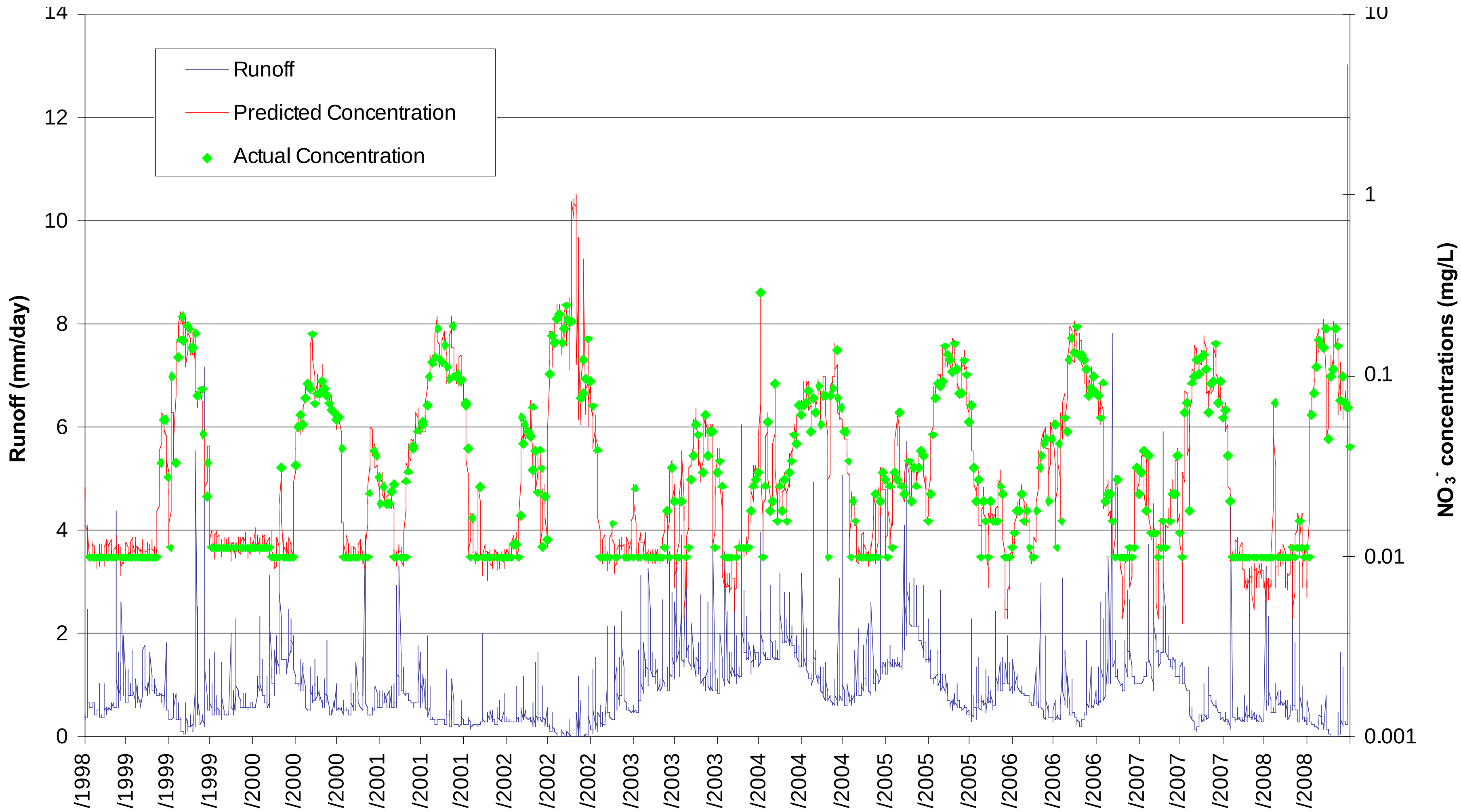


- What is the space/time distribution of nutrient sources in urban watersheds?
  - Where do nutrient loads come from, and what are the sources?

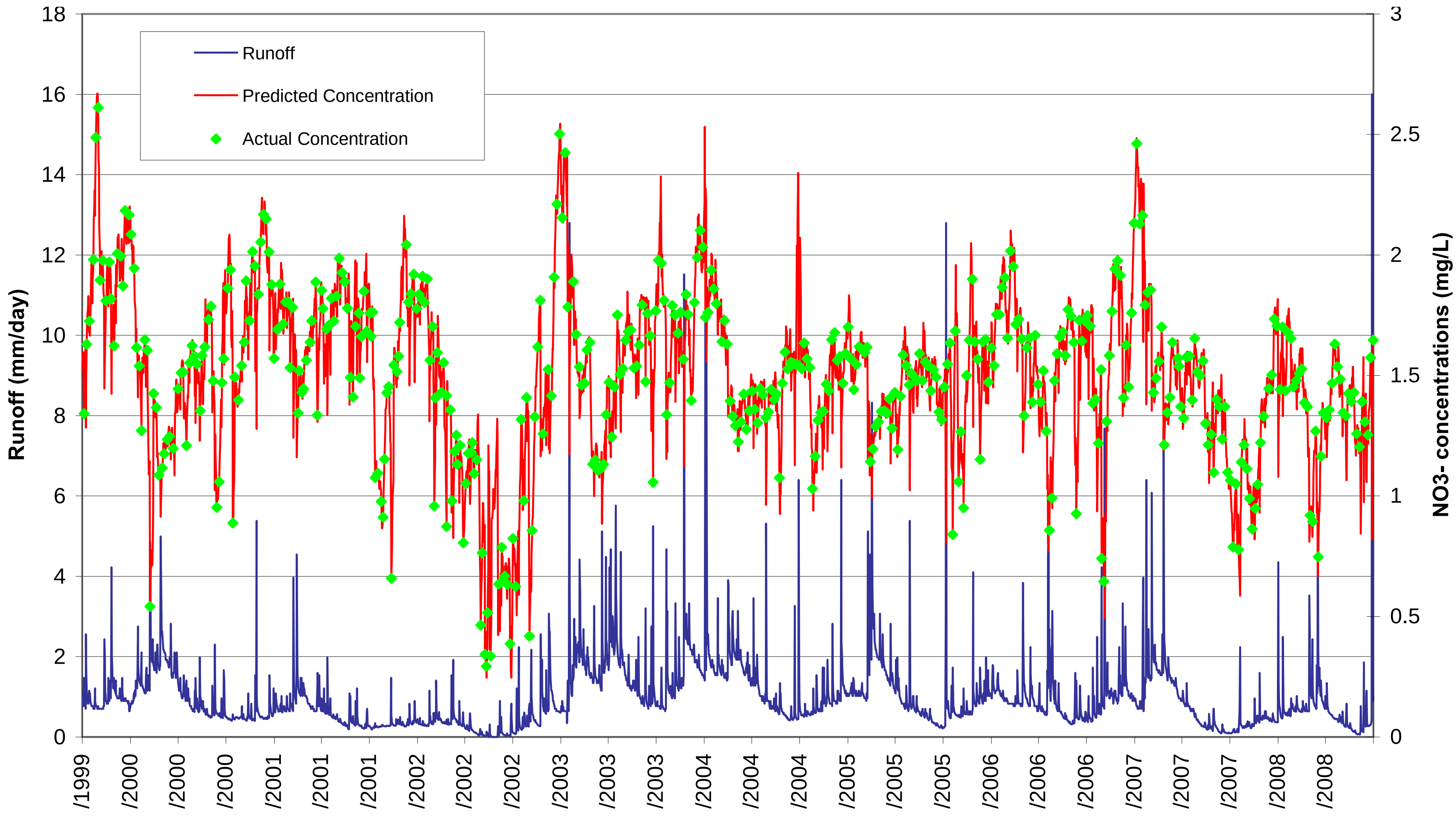
- How are nutrient cycling and export coupled to carbon and water cycling?
  - Under what hydroclimate conditions are nutrients mobilized, transported from source areas? Low/high flow? Wet/dry conditions? Seasons?
  - What key ecosystem processes and features determine sources and export?

High flows provide additional N, P sources through pressurized surcharging of sanitary sewers

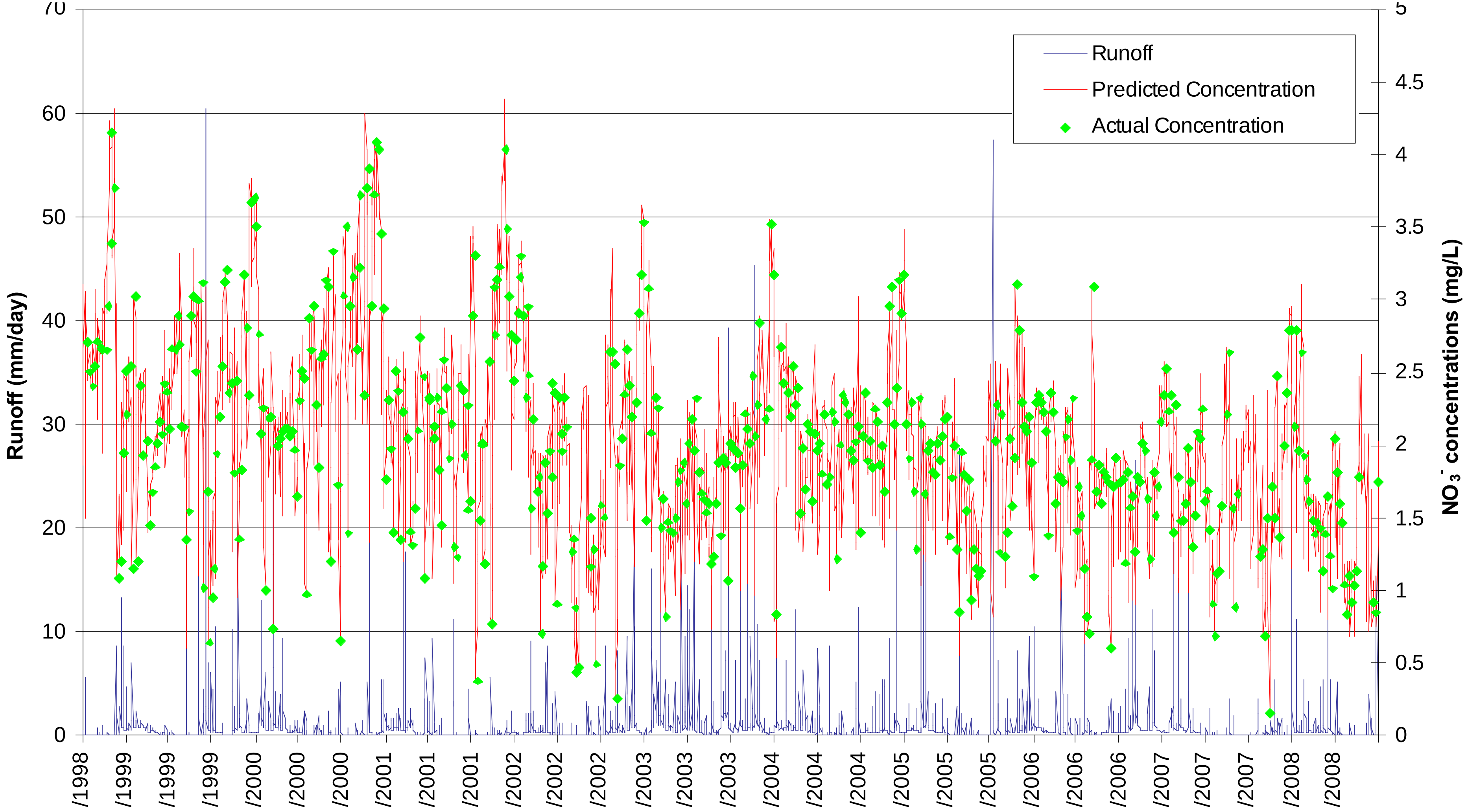
Forested catchments, low flow and NO_3 concentrations and variability



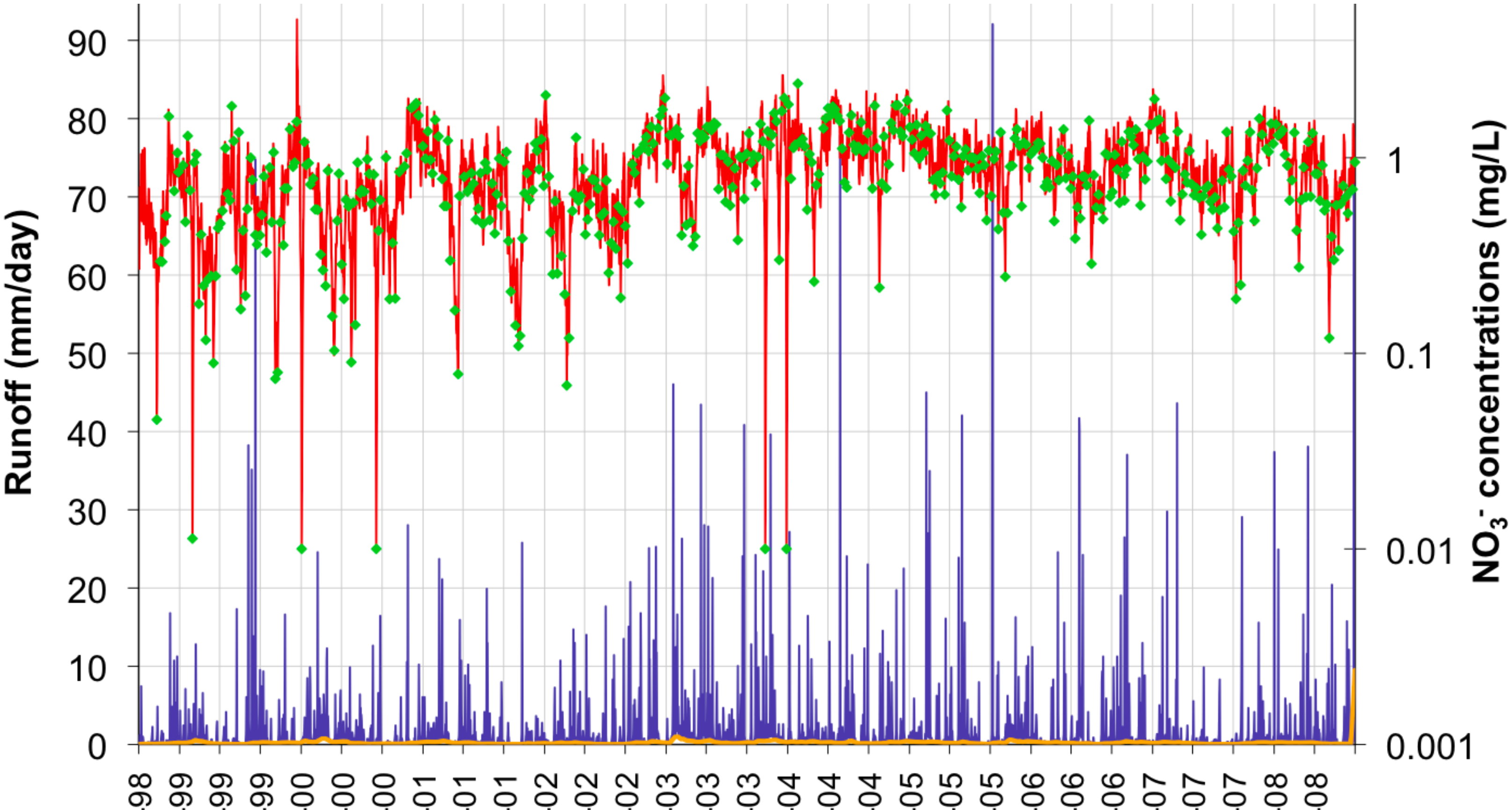
Low density suburban (2/3 forest) on septic, low flow, high NO_3, low variability



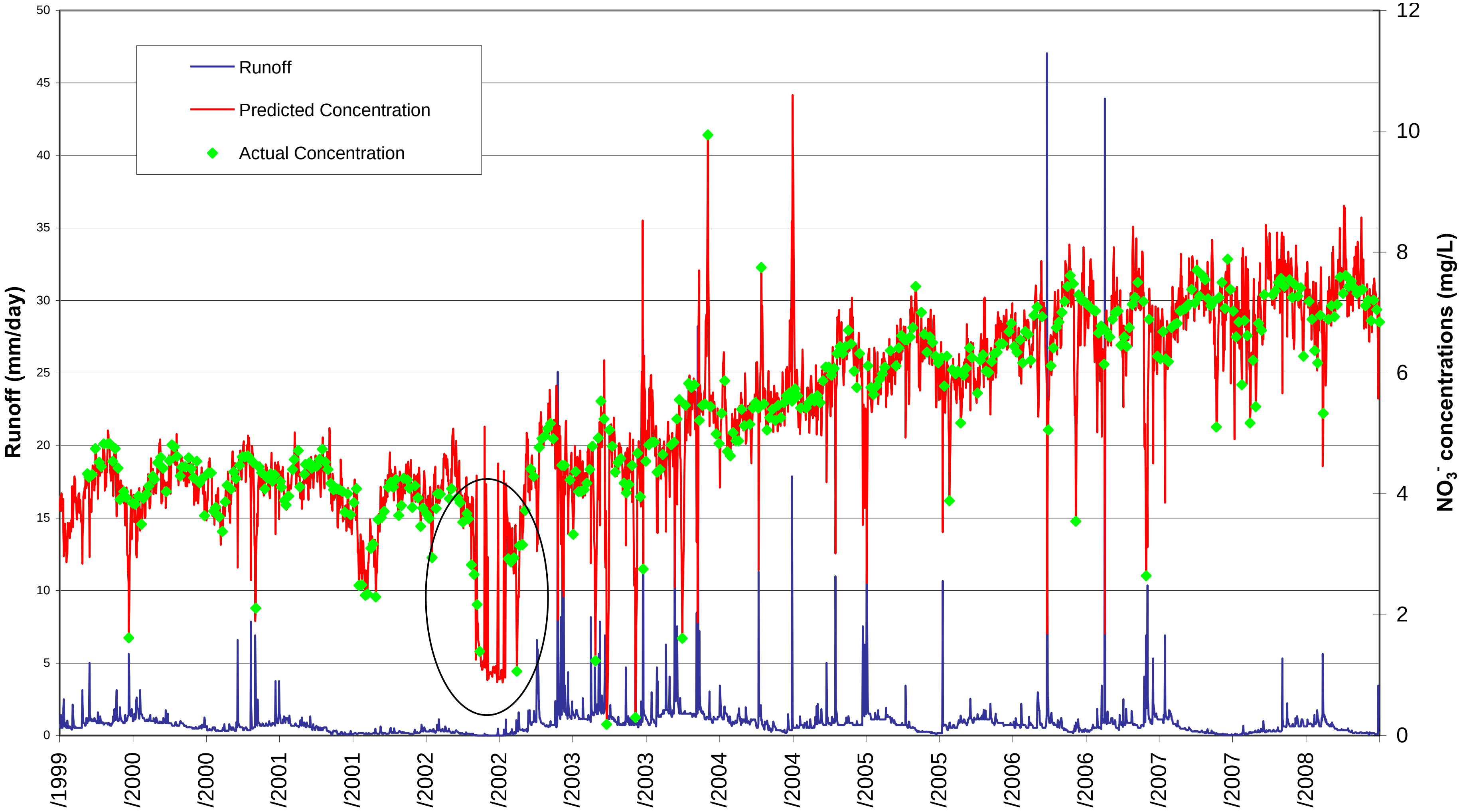
Medium density residential, high flow and [NO_3] variability

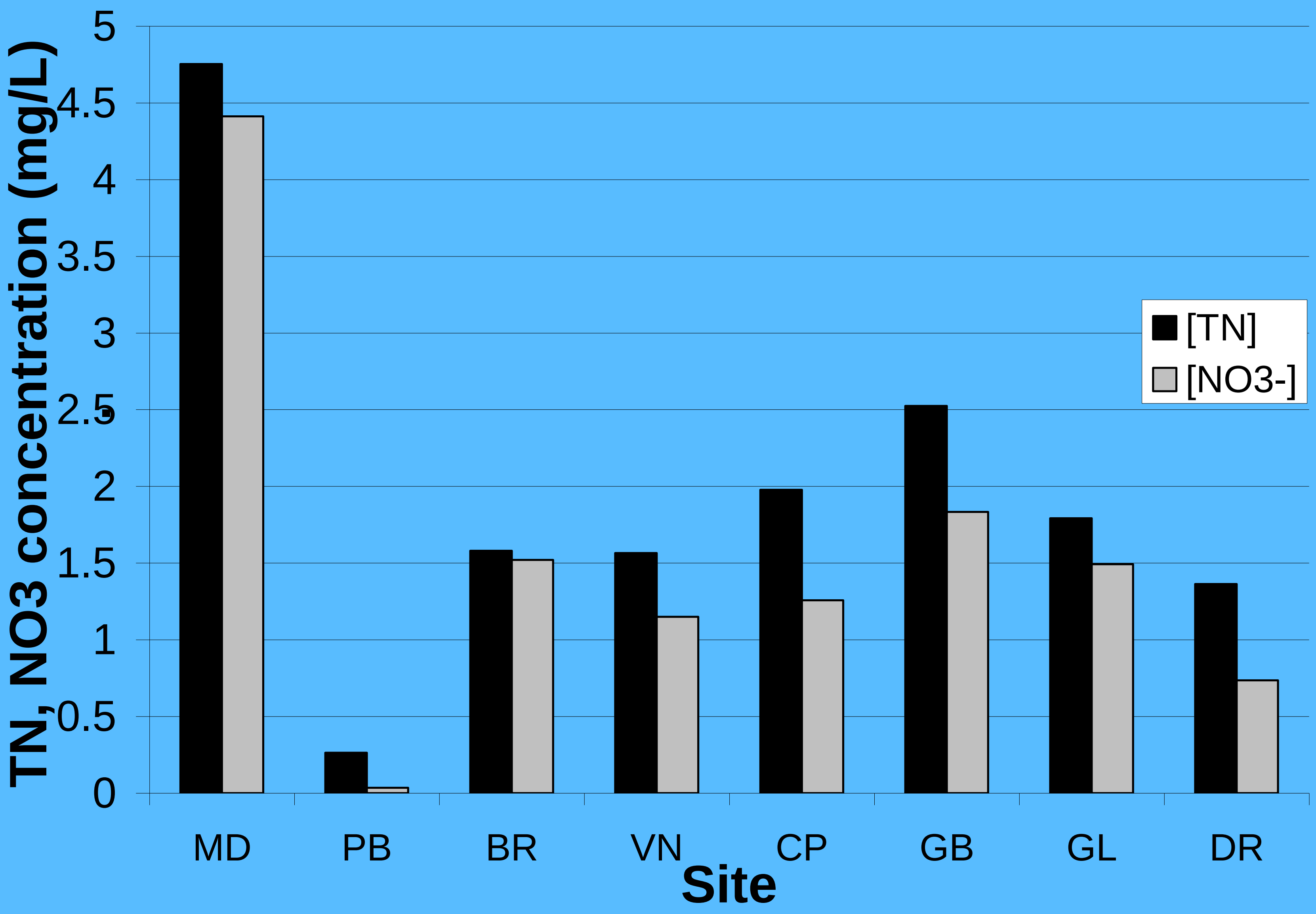


Dead Run flow and NO_3^- concentration time series

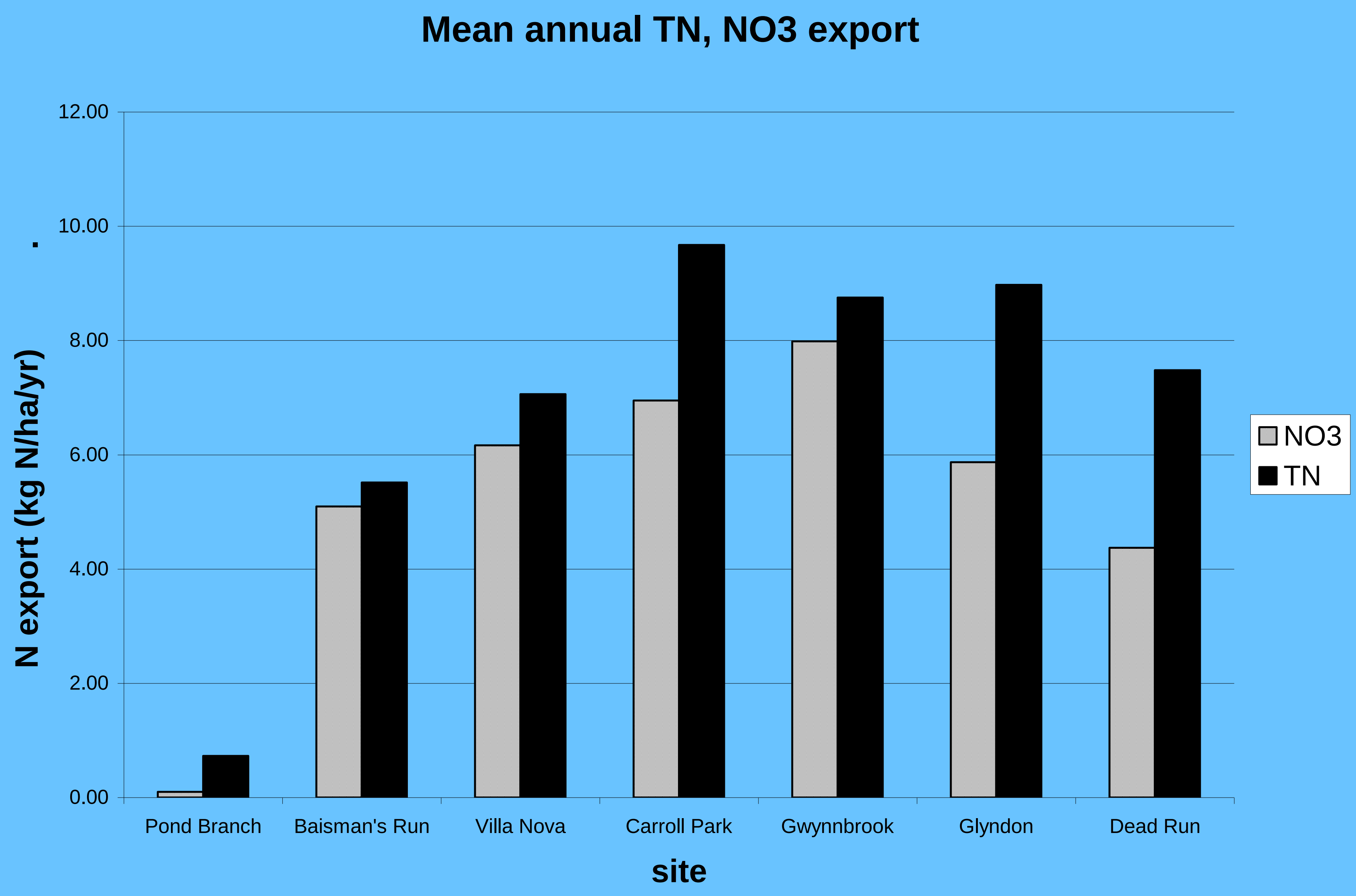


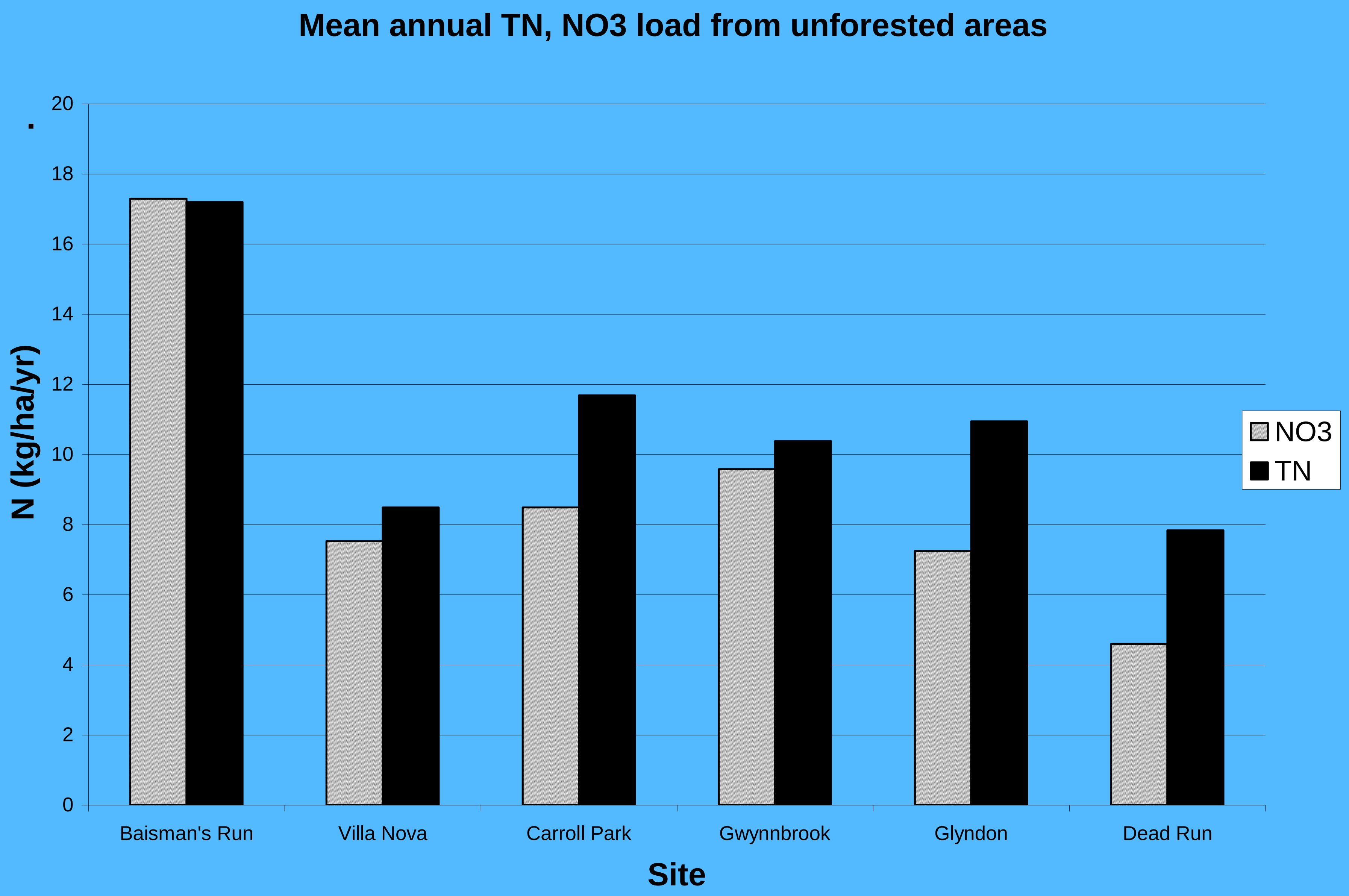
Agricultural catchments, low flow, high NO_3 concentrations, low variability





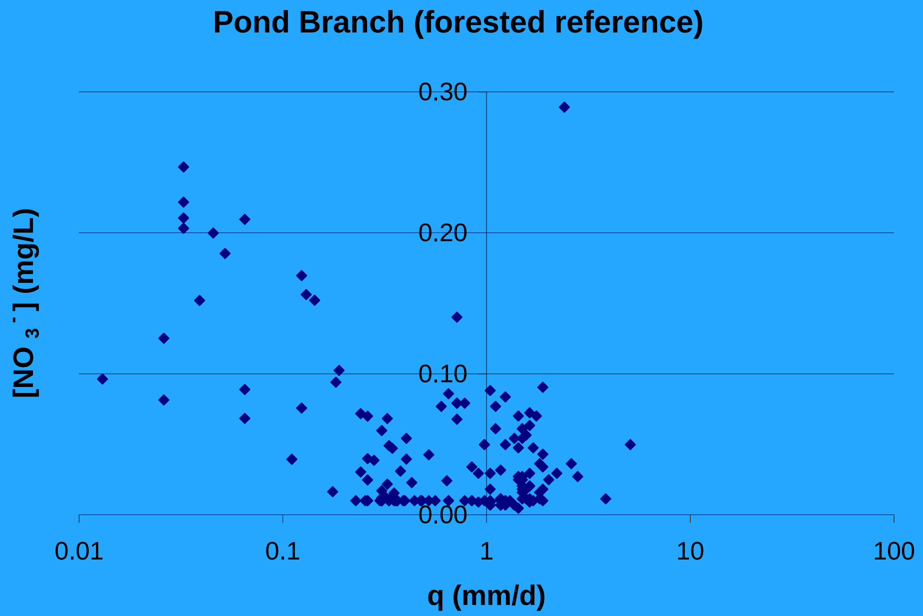
Shields et al 2008, WRR

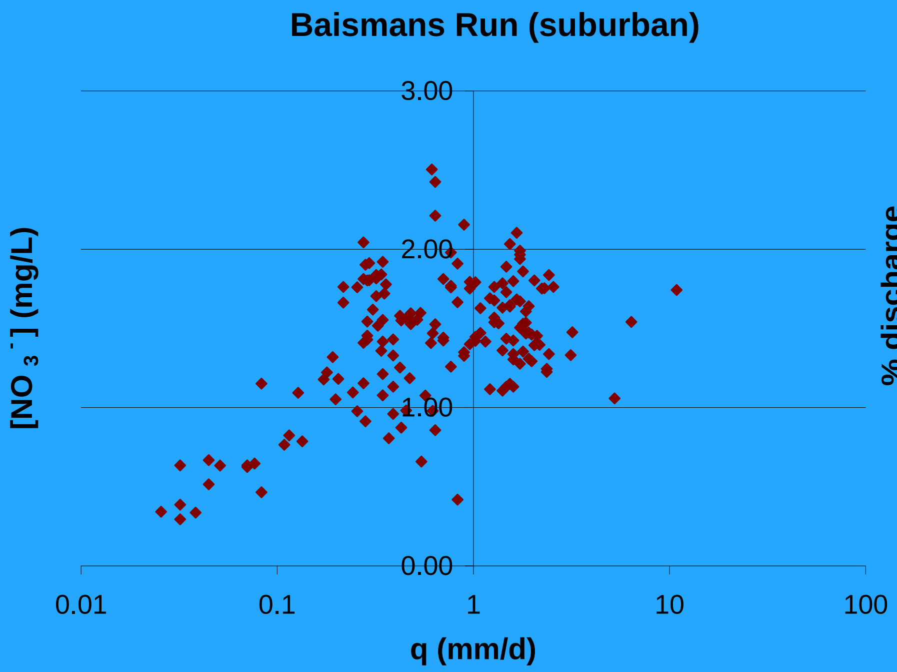

Mean annual TN, NO3 export
N export (kg N/ha/yr)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Pond Branch
Baisman's Run
Villa Nova
Carroll Park
Gwynnbrook
Glyndon
Dead Run
site
NO3
TN

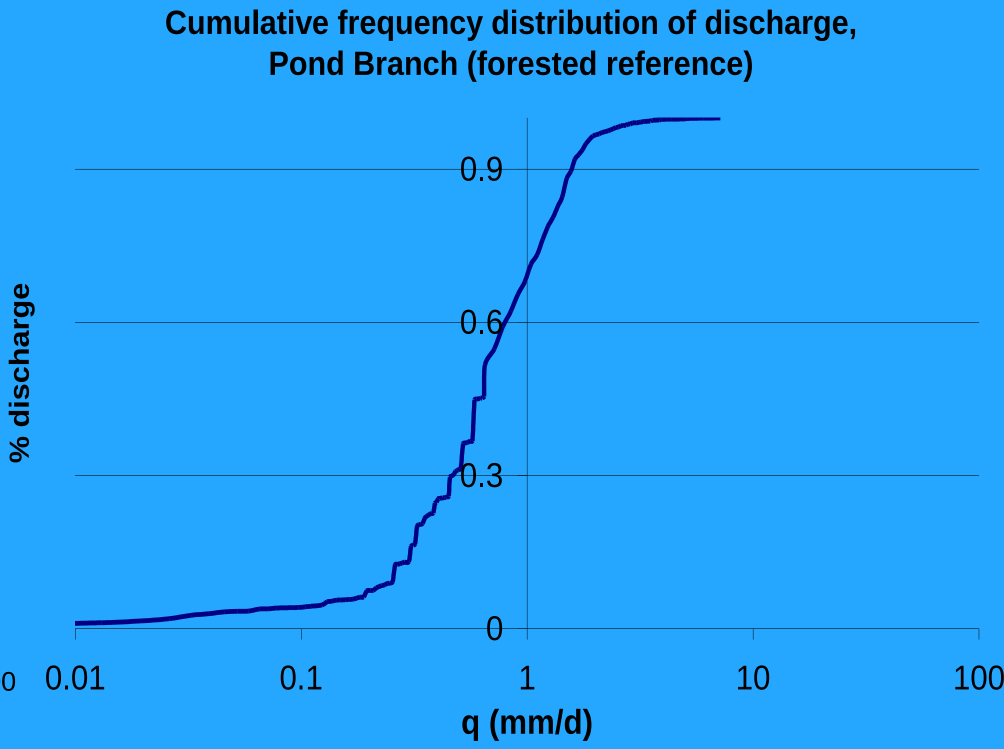


Mean annual TN, NO3 load from unforested areas
N (kg/ha/yr)
20
18
16
14
12
10
8
6
4
2
0
Baisman's Run
Villa Nova
Carroll Park
Gwynnbrook
Glyndon
Dead Run
Site
NO3
TN

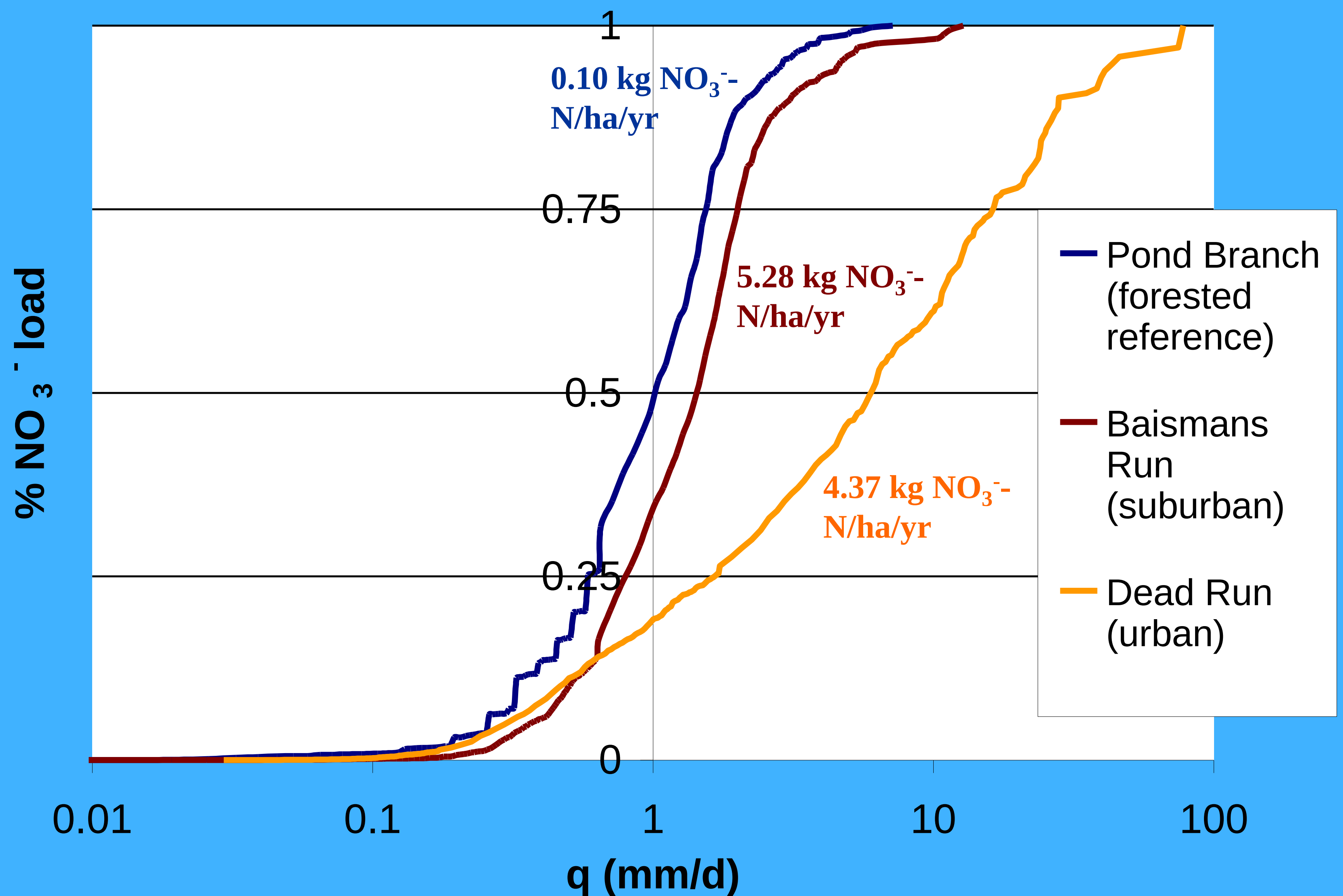
Cumulative export of N with flow developed from N concentration-discharge relations and flow duration



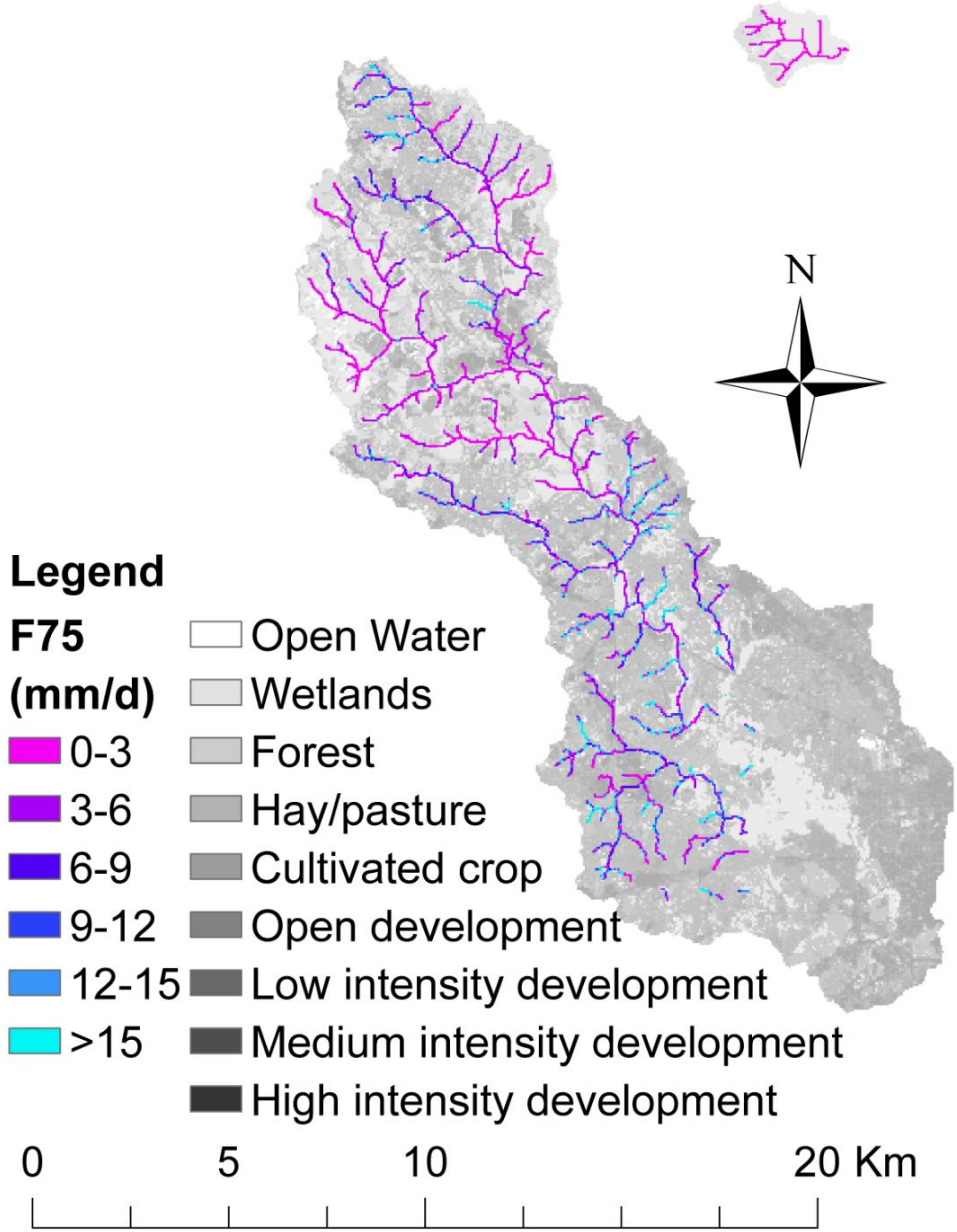




Export distribution varies with land cover



Shields et al 2008, WRR



N
Legend
F75
(mm/d)
0-3
3-6
6-9
9-12
12-15
>15
Open Water
Wetlands
Forest
Hay/pasture
Cultivated crop
Open development
Low intensity development
Medium intensity development
High intensity development
0
5
10
20 Km

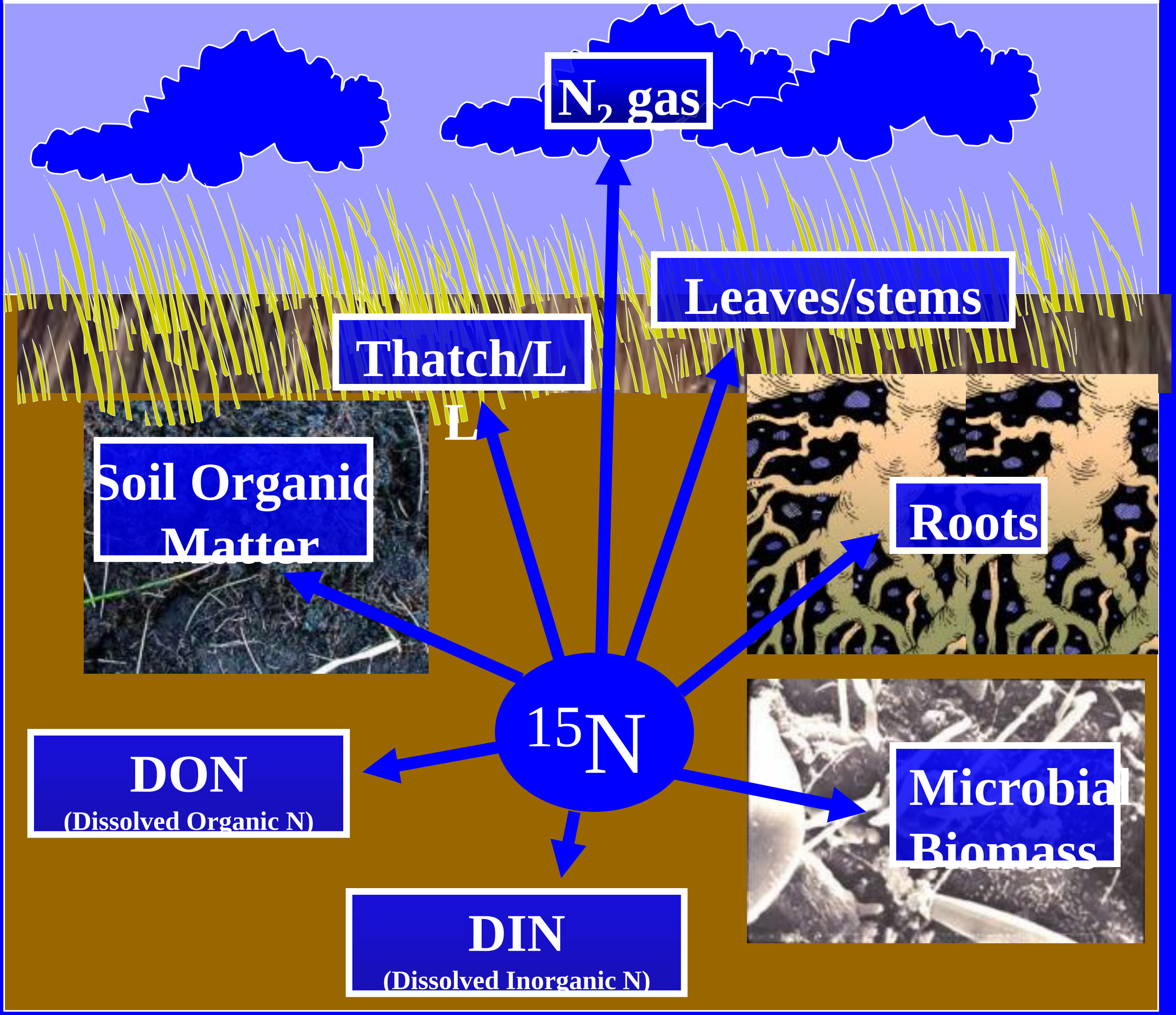
Glyndon – 81 ha, mix of older suburban, new developments
What are the sources of N?

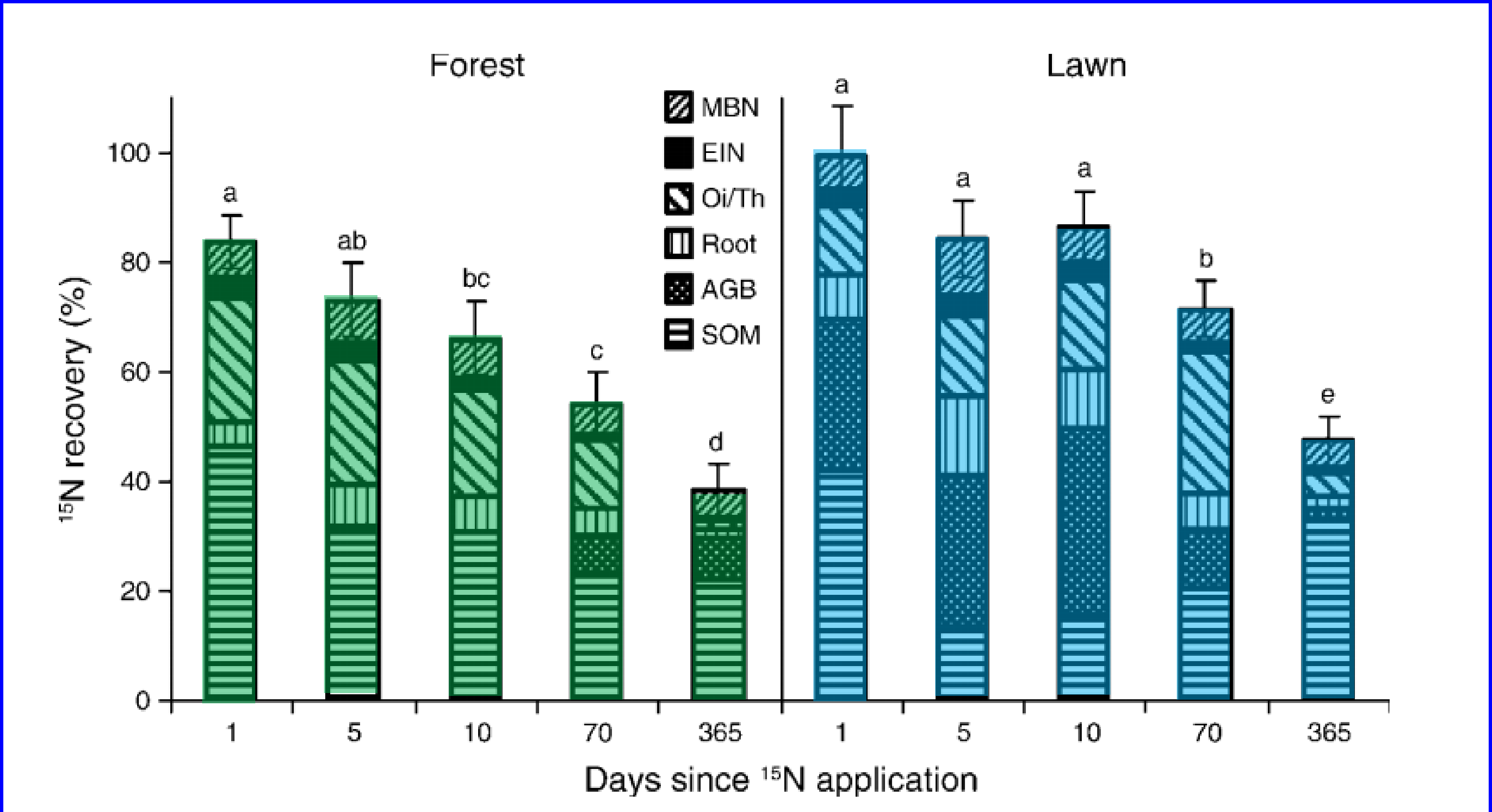
N retention in lawns?

Steve Raciti, BU

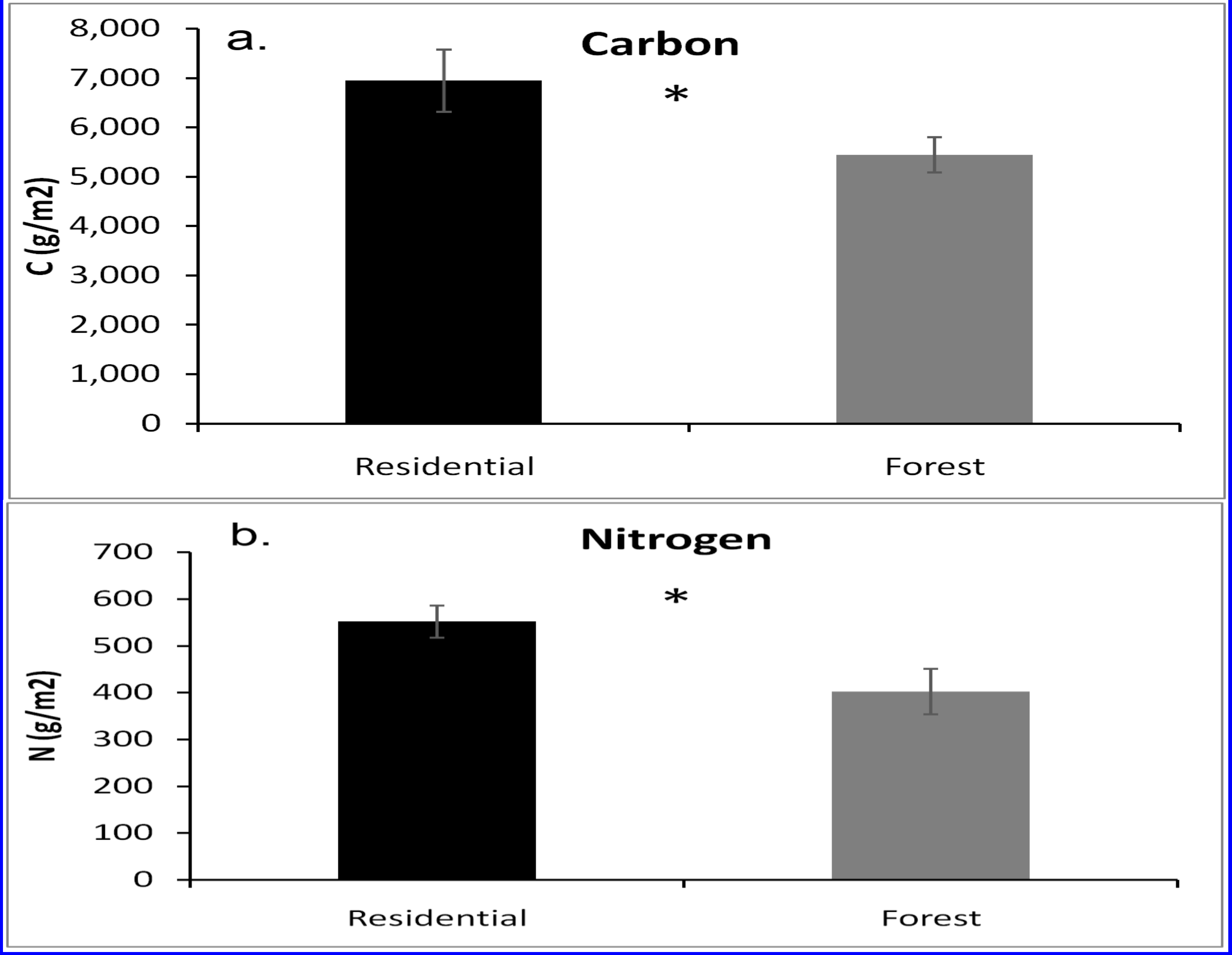
- N sources to BES watersheds
  - Fertilizer = ~14 kg/ha/yr
  - Atm Deposition = ~12 kg/ha/yr
    - Largely from fossil fuel combustion
- **Tracer Experiment**
  - Simulate atmospheric N deposition
    - Spray ^{15}N 'labeled' nitrate on lawns & forests
  - Compare N retention
- Labeled N?
  - N has 2 stable forms: ^{14}N, ^{15}N
    - Ambient: 0.4% ^{15}N atoms
    - Labeled: 99.5% ^{15}N atoms
  - Can follow the N through the system…

Following the 'Labeled' Nitrogen





- Retention of simulated atmospheric N deposition was similar in lawns and forests
  - Despite annual fertilizer applications to lawns



Residential soils had more carbon and nitrogen than forest soils.

Raciti et al, 2011

Lawn fertilization rates by watershed area (mpw), residential area (mpr), lawn area (mpl)

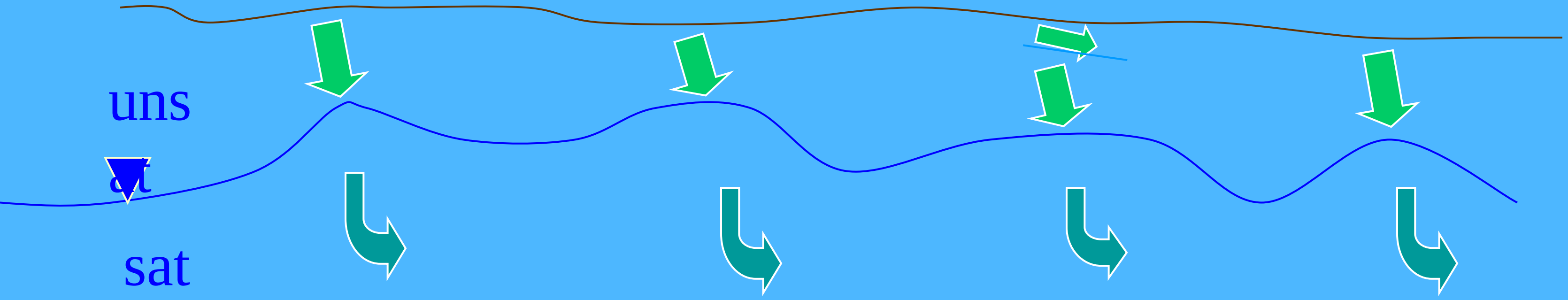
Table 4. Application rate of fertilizers to lawns at three spatial scales

Application rate (kg N/ha/yr) Scale[1]	Glyndon	Baisman Run
Watershed (mpw)	12.5	9.5
Residential land use (mpr)	26.7	27.8
Lawn cover (mpl)	83.5	37.1

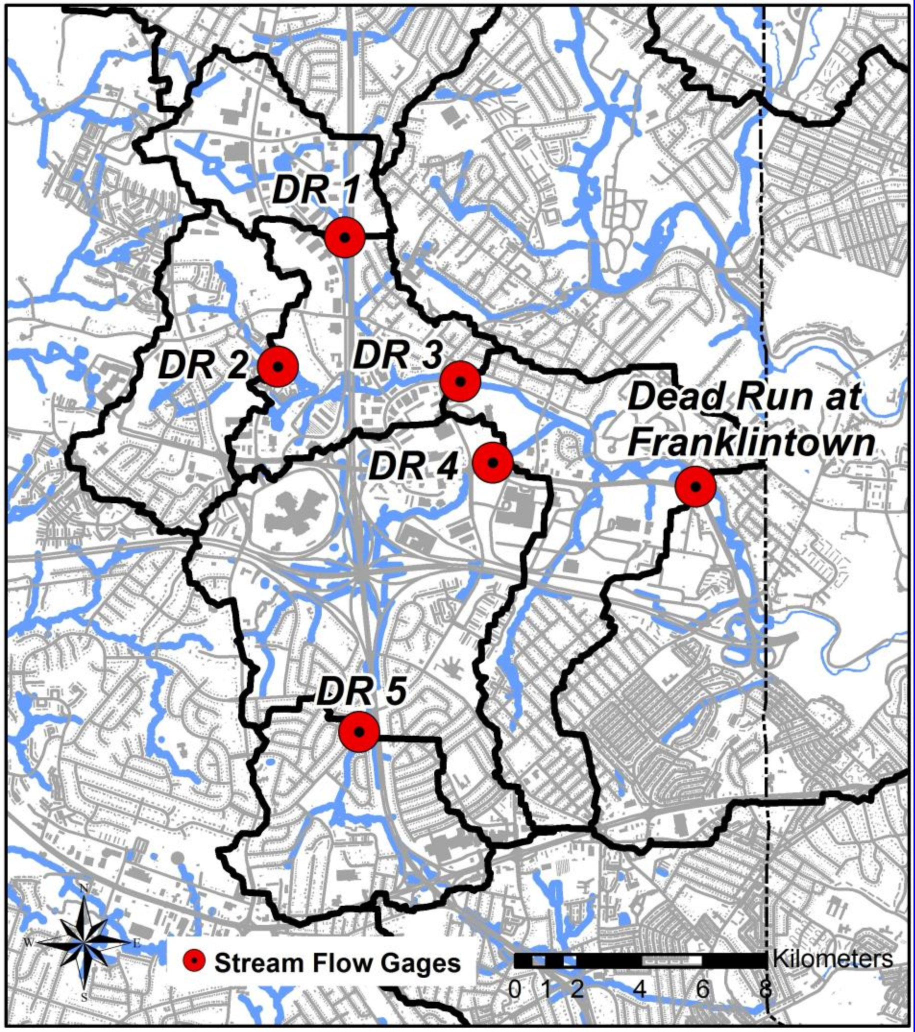
Note: [1]The spatial scale is an expression of the aerial aggregation of the watershed area, total residential land-use area within each watershed and total lawn area within each watershed. Each different scale is abbreviated as mass per unit watershed, mass per unit residential land use or mass per unit lawn area as, mpw, mpr, and mpl, respectively.

Nested (sub)urban flux fields

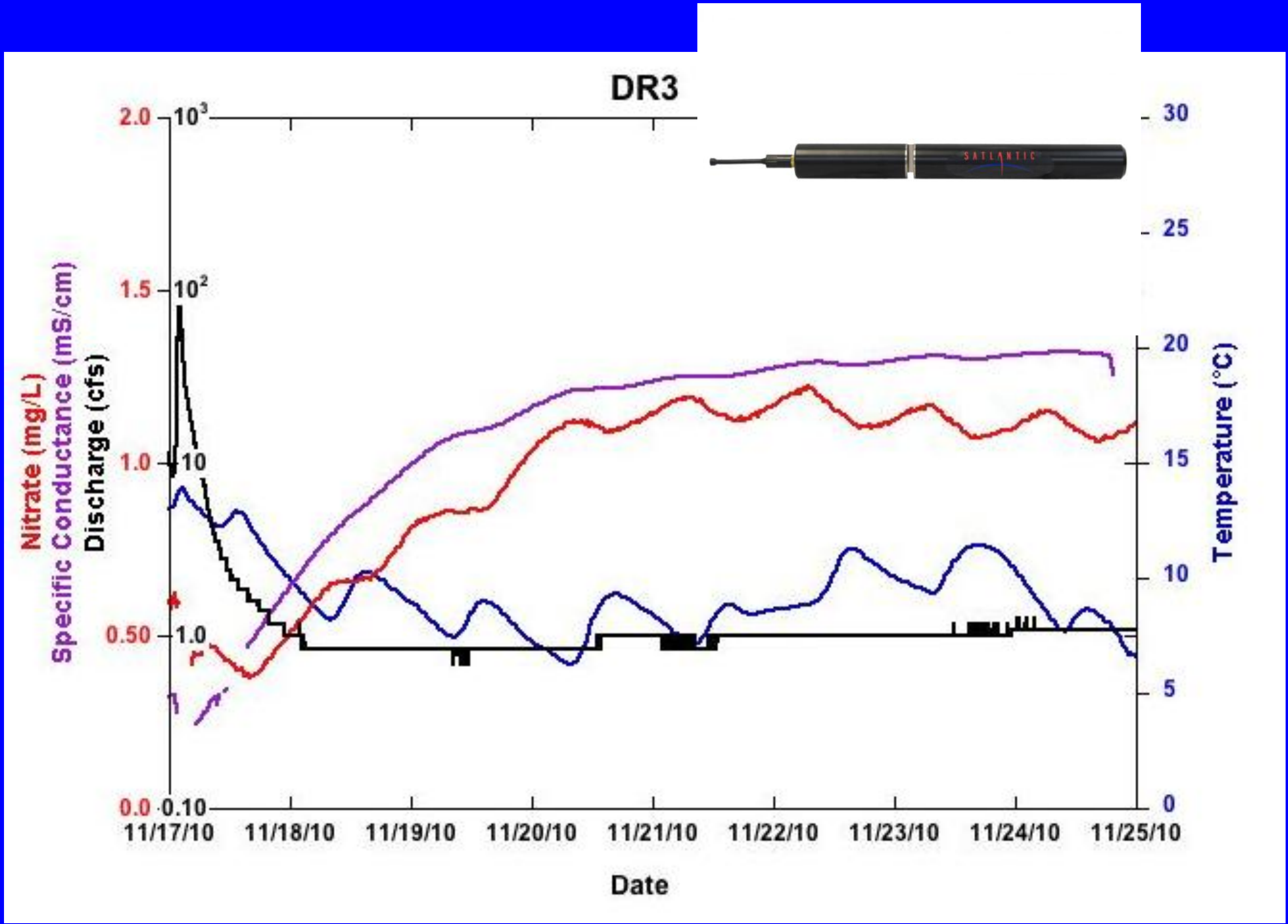
- Regional annual precipitation/deposition: ~1000 mm
  - ~8-10kg N/ha/yr 100% land area
- Lawn irrigation: 25mm/wk *20weeks ~ 500 mm 20-50%
  - ~100kg N/ha/yr 30-50% land area
- Septic input: 600 l/day /100 m^2 = 6 mm/day >2000mm / yr
  - ~ .02-.03 kg/100 m^2 /day ~900 kg/ha/yr (mpsa) ~9kg/ha/yr (mpr)



Verhoef, Welty, et al
UMBC

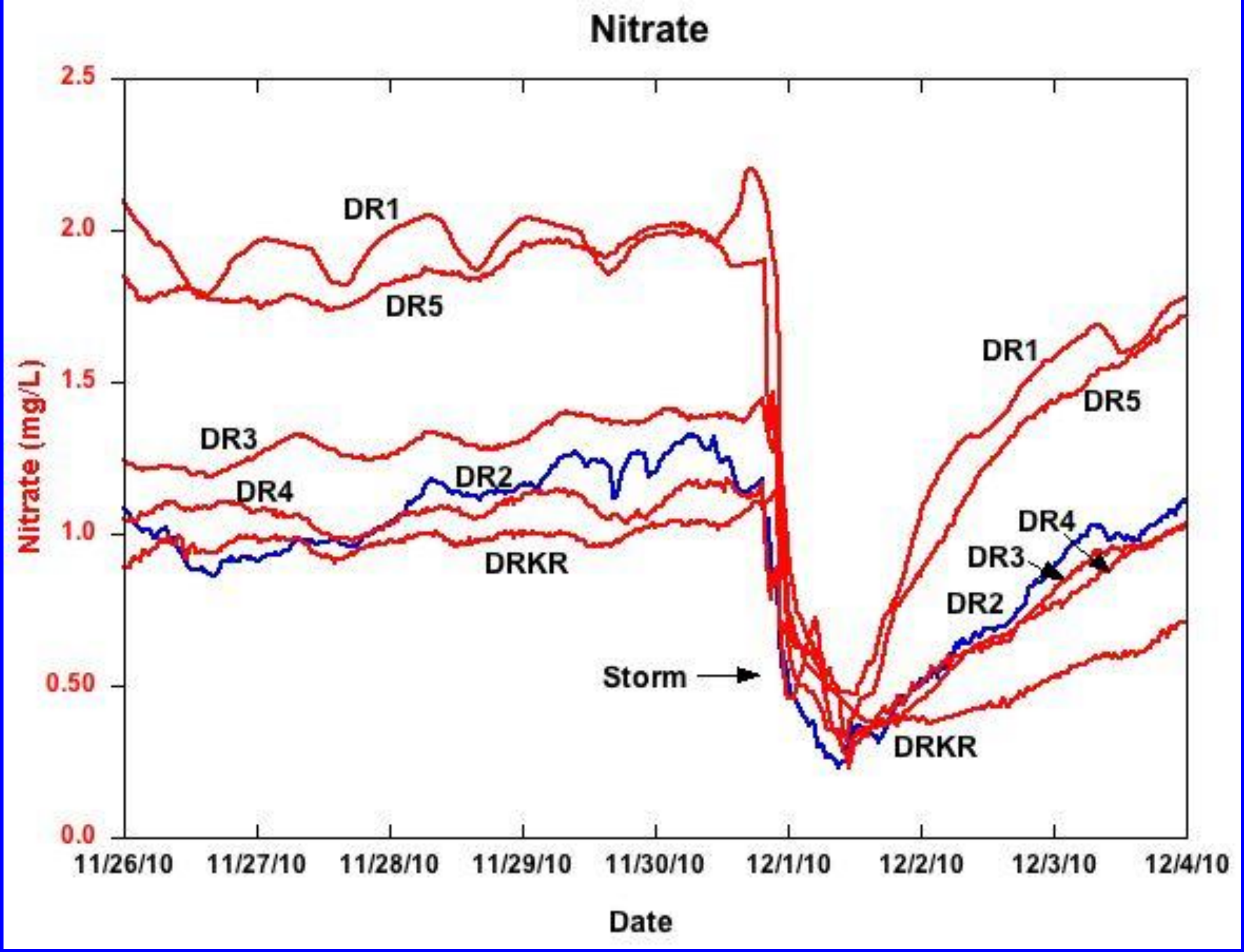


High frequency UV-nitrate sensor monitoring of storm and diel dynamics



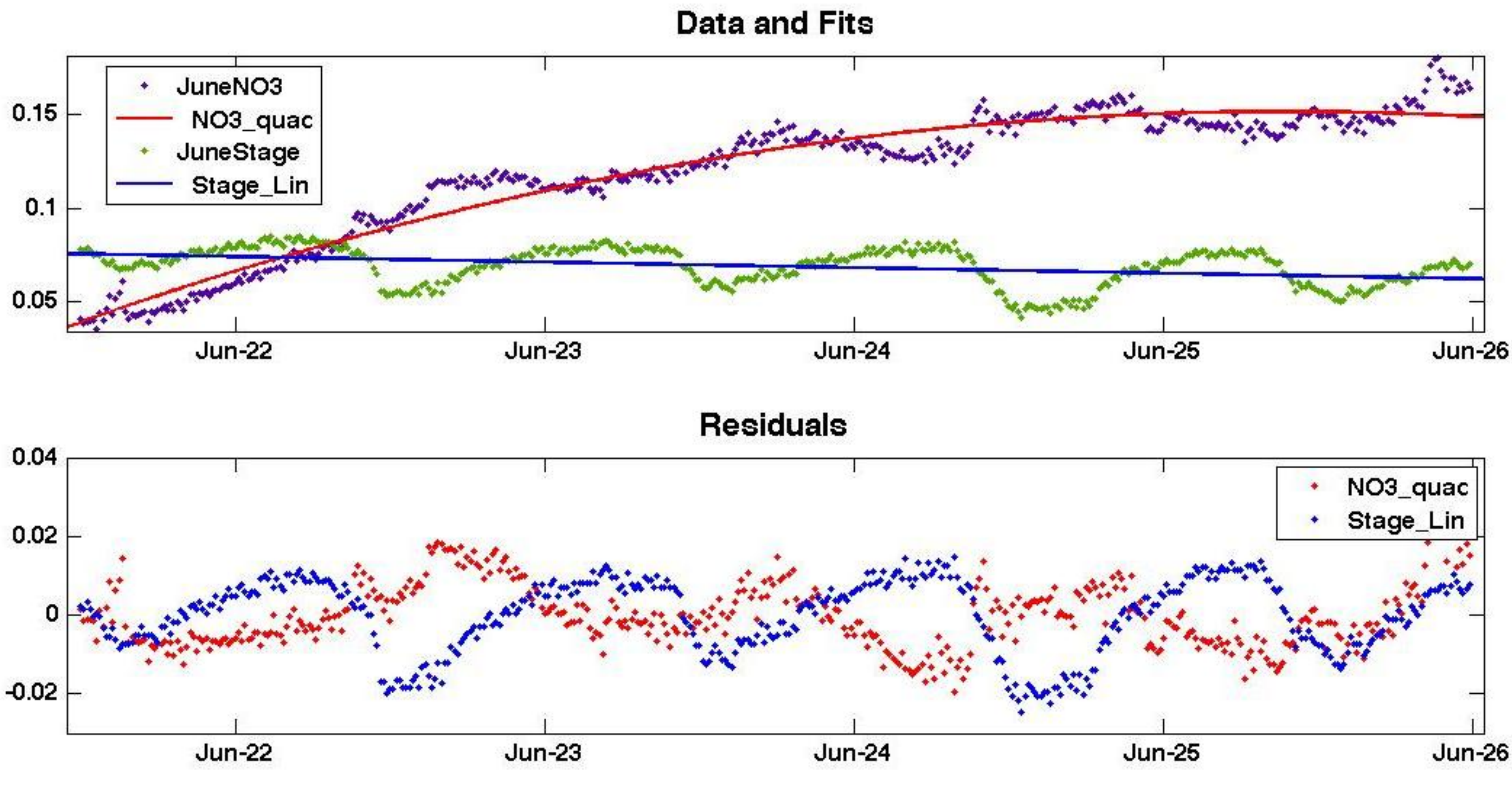
VerHoef et al., 2011a,b; VerH

Storm dilution and recovery of NO_3^- in Dead Run catchments. Diel variations expressed differentially across streams



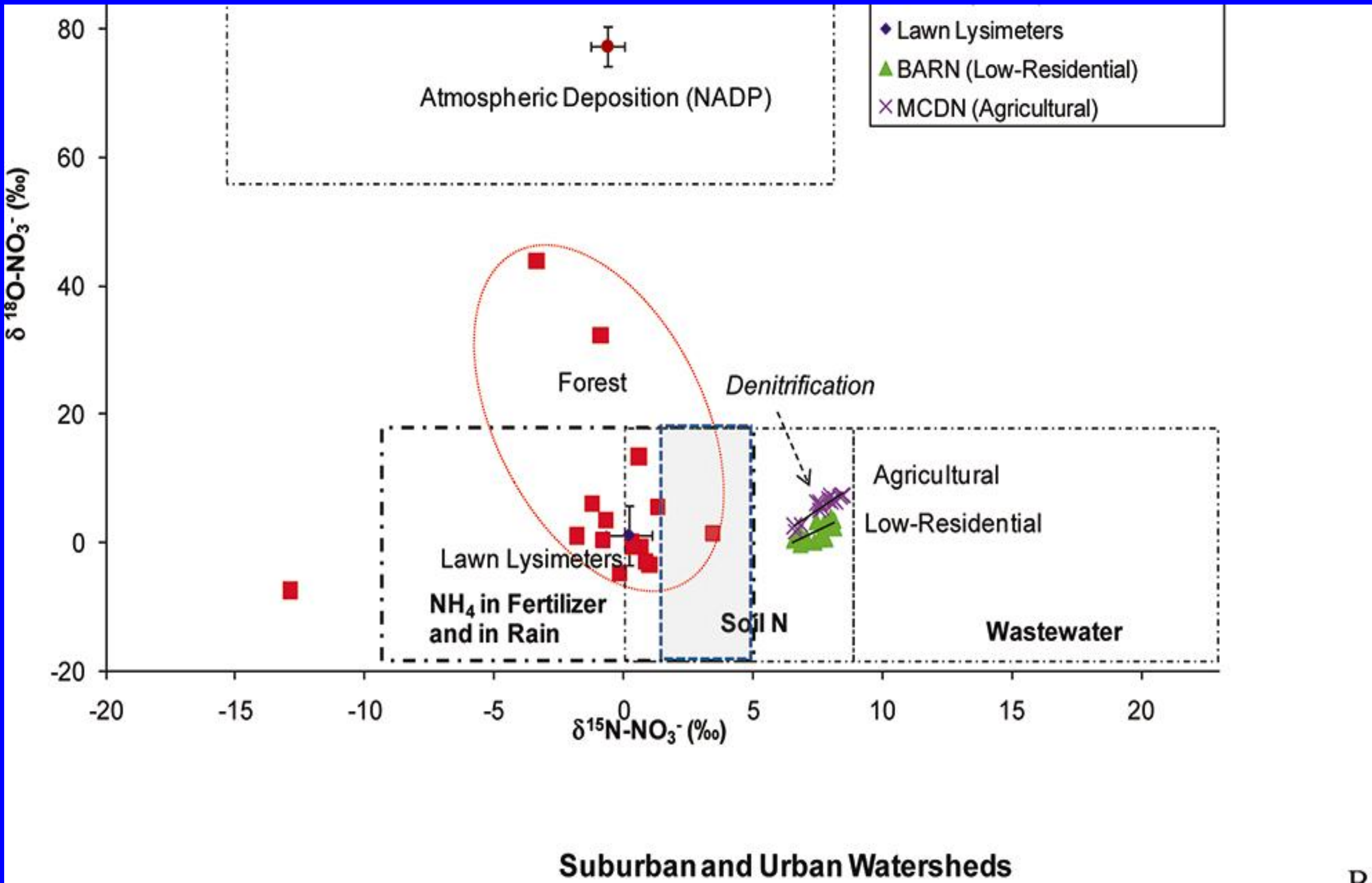
VerHoef et al., 2011a,b

Hi frequency SUNA measurements of diel variations of NO_3^-

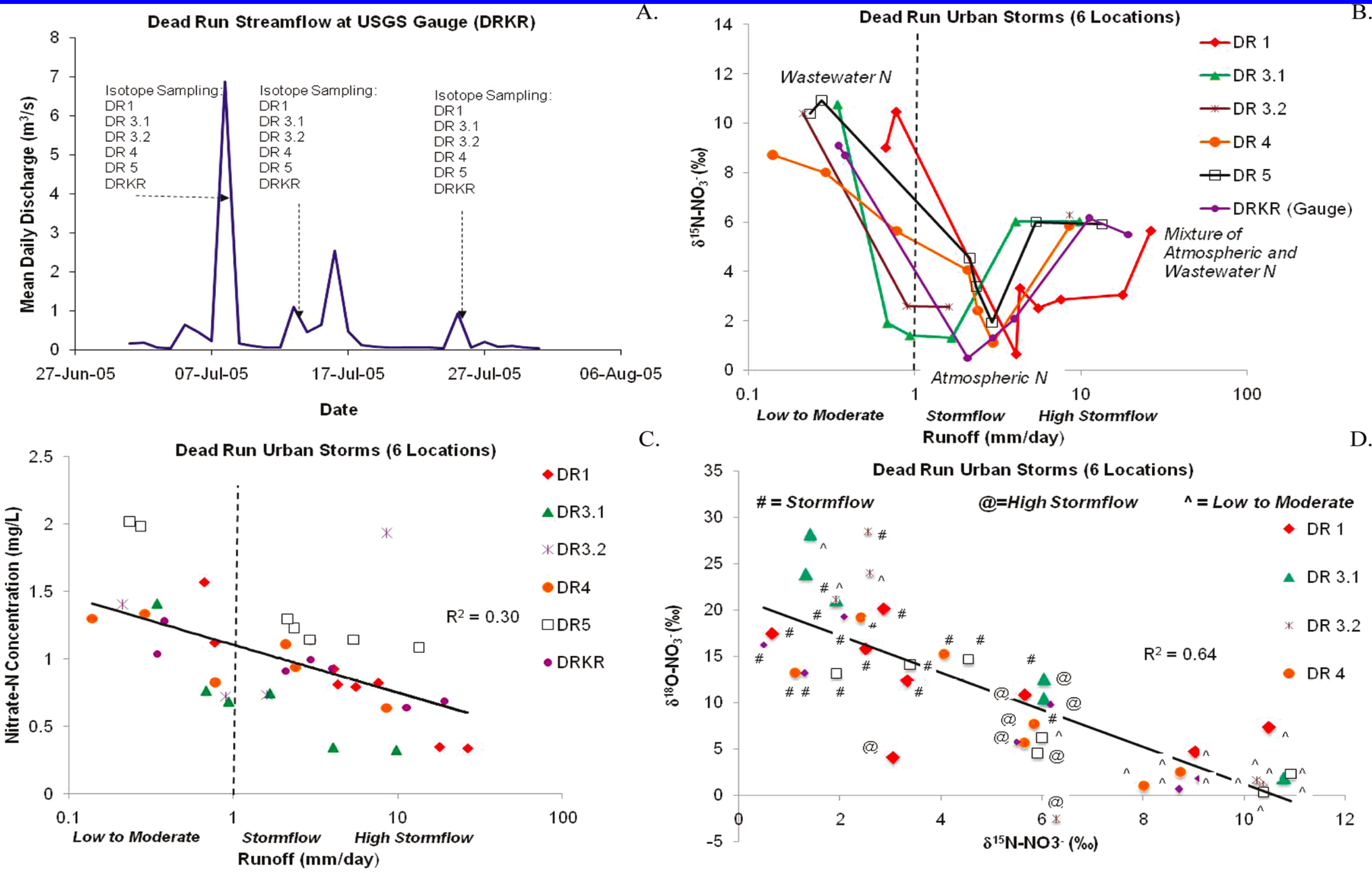


Dual isotope signatures of nitrate from different sources and catchments

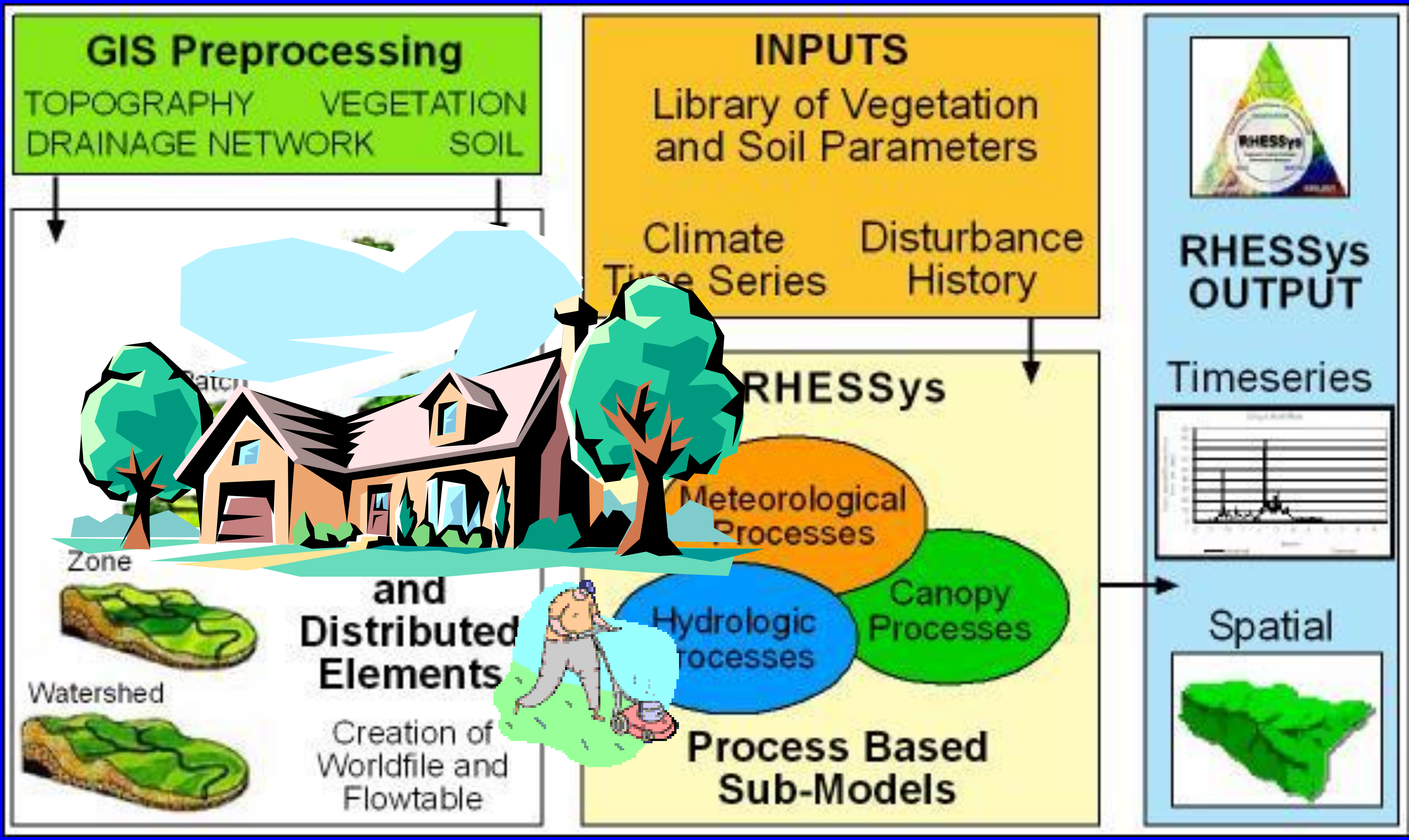
Kaushal et al, 2011, ES&T



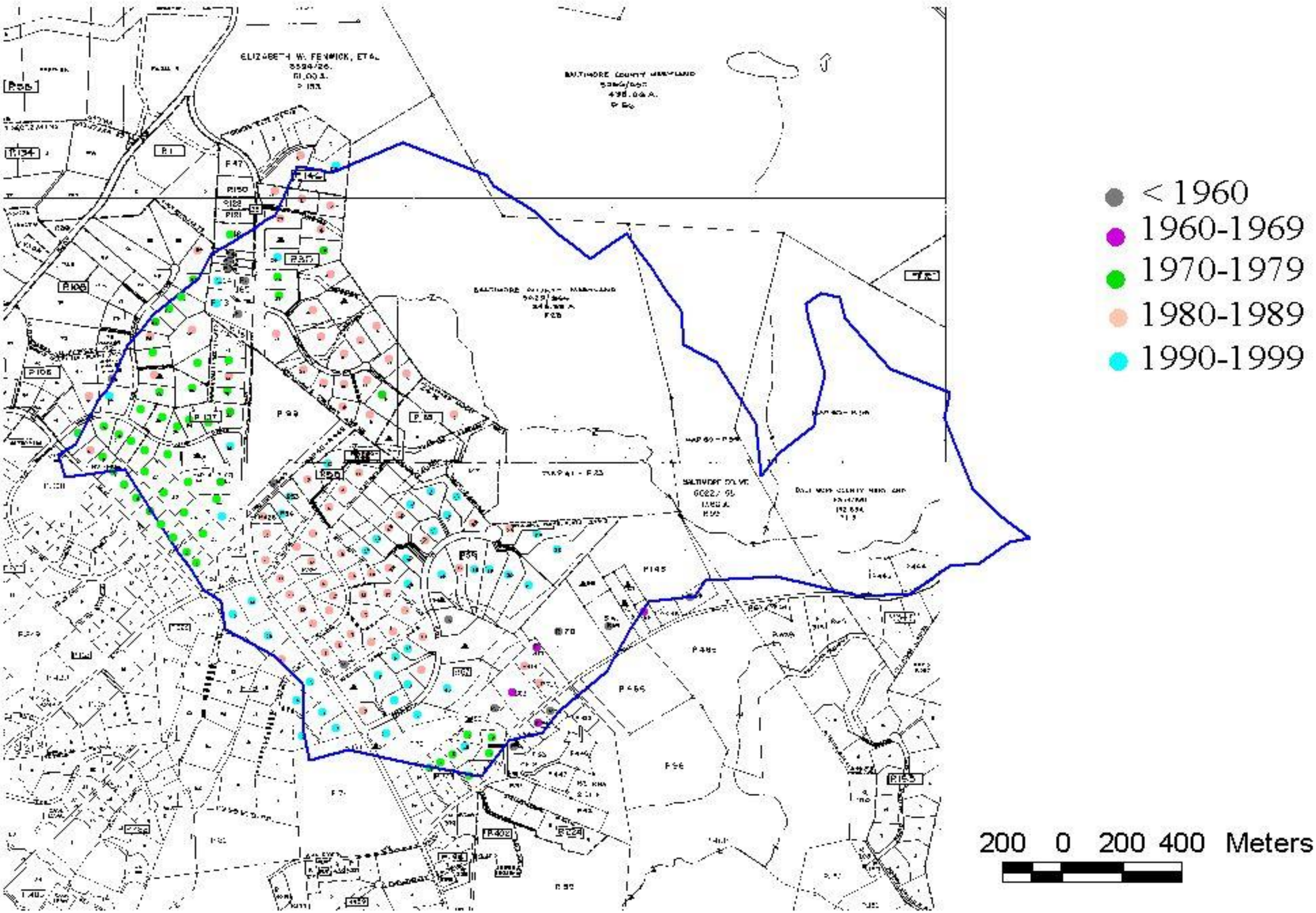
Mixing and transition of dominant N sources with flow levels - Kaushal et al 2011, ES&T



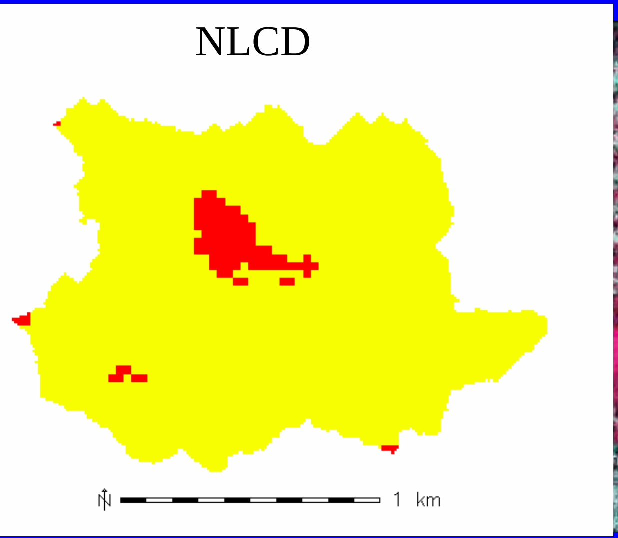
RHESSys Flow diagram

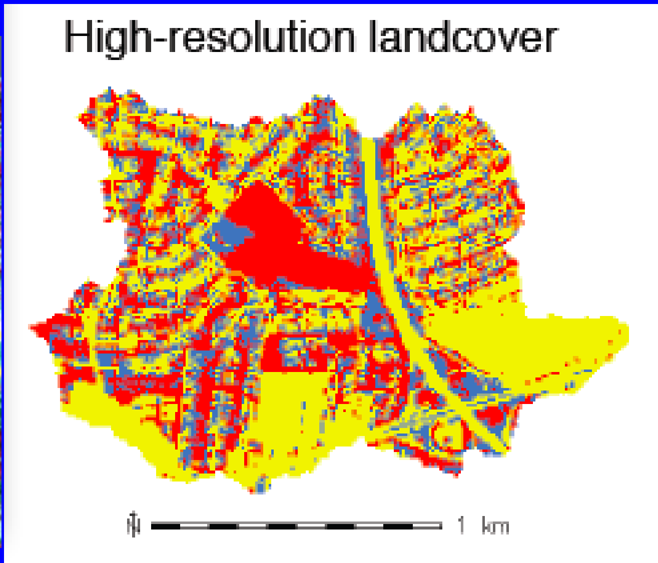


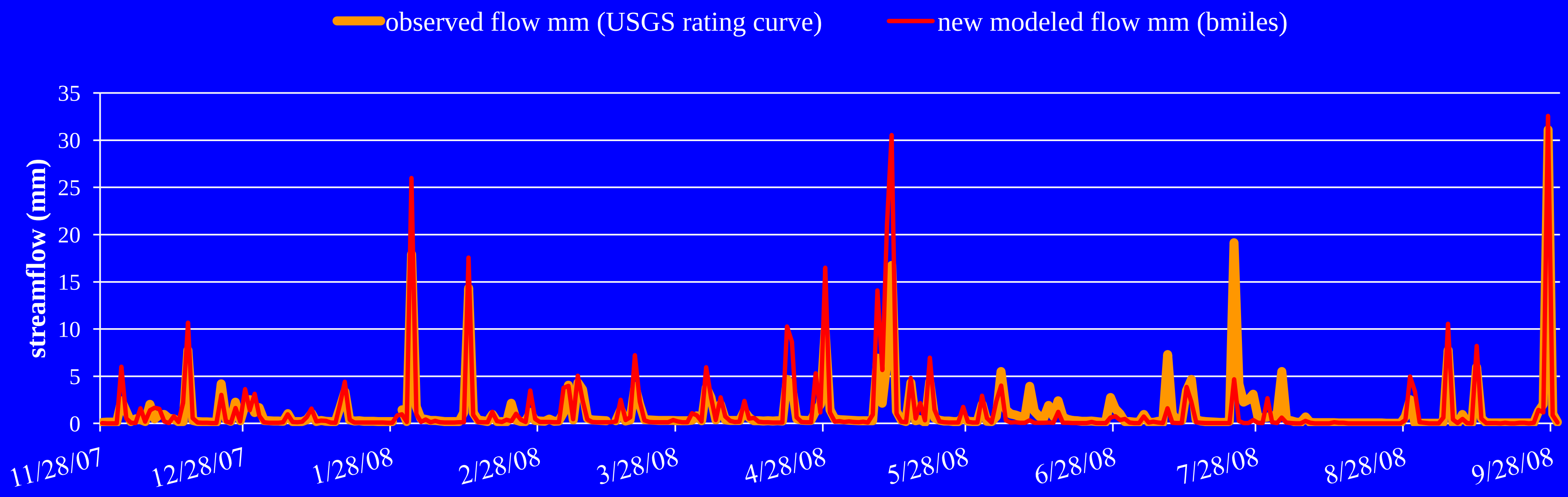
Baismans Run watershed: Year house built



Dead Run 5: Hi res object-oriented land cover







When, what and where of nitrogen exports
Interaction with water, carbon cycling
Prospects for improved retention

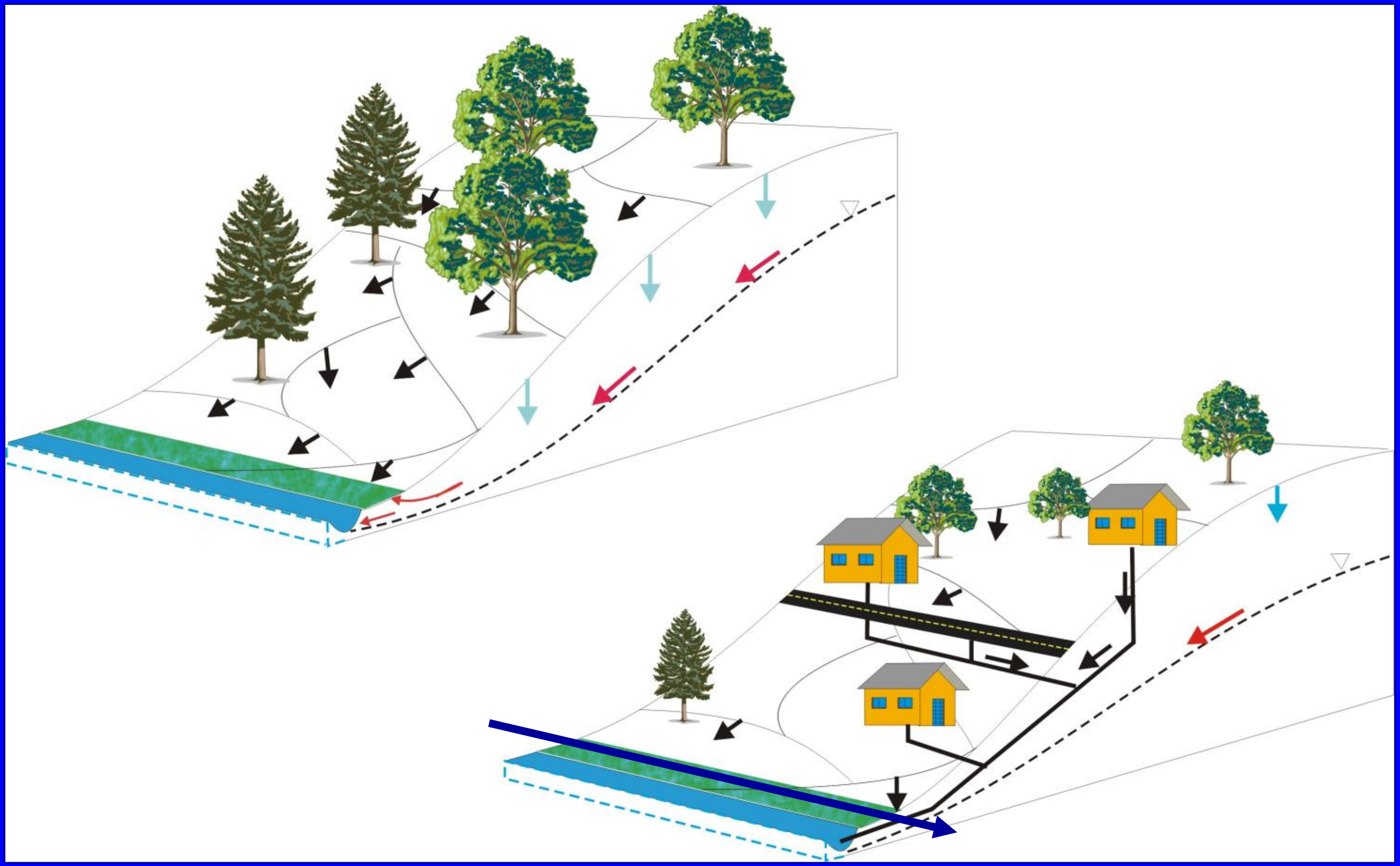
- On site (septic) and sanitary sewer wastewater appear to dominate.
  Lawns appear to be more conservative in carbon/nitrogen than expected

- Mixed low density areas beyond urban service boundary (extensive in expanding suburbs/exurbs) have large export at moderate to low flow.
  - Potential to increase in-stream retention if flow rates can be reduced or contact with riparian areas can be restored.

- Highly developed catchment N export increases significantly at higher flows, dominated by large events
  - More limited potential to achieve N reduction through restoration
  - Altering catchment flow regime, reduction at source required

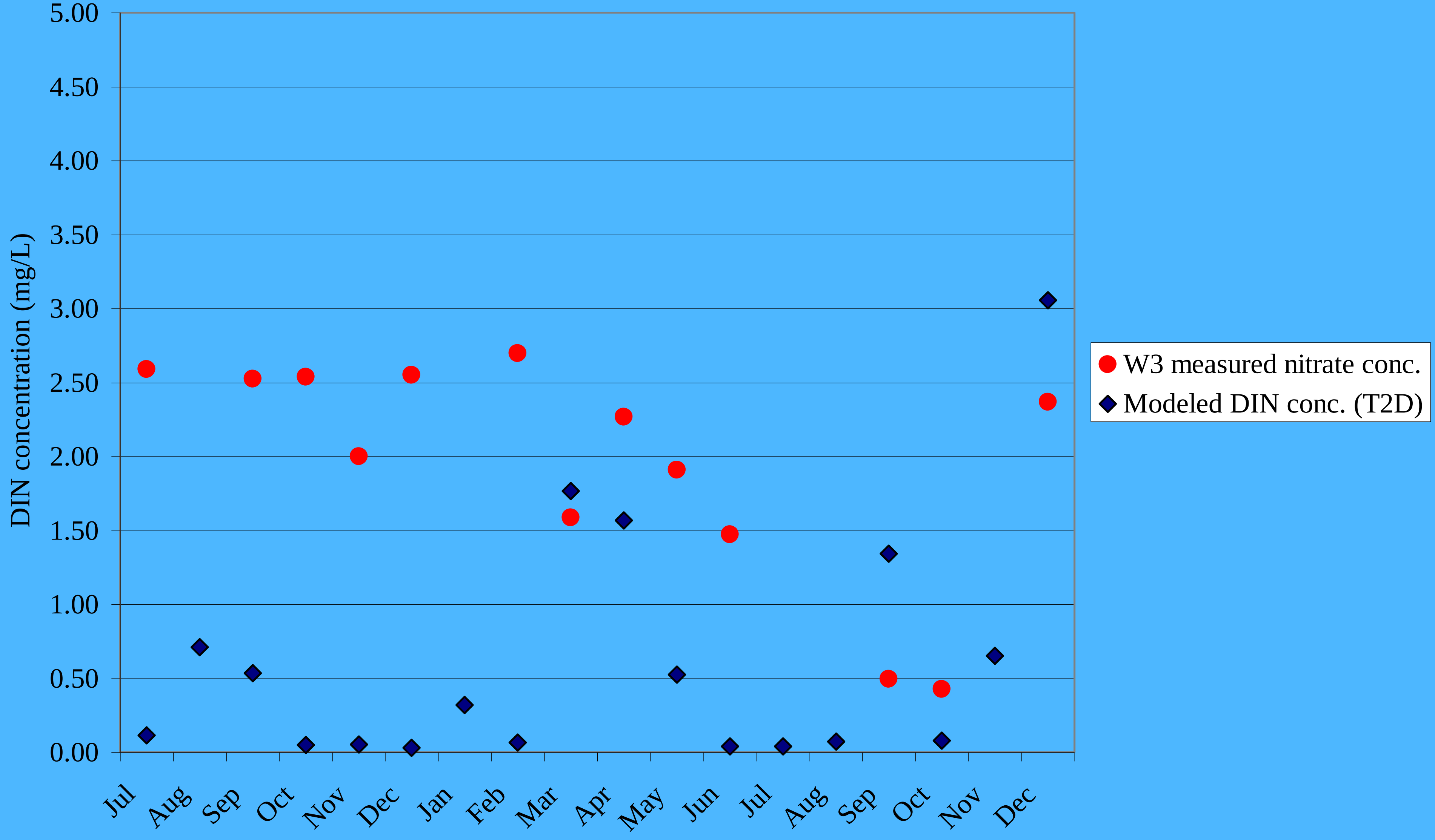
- Drought promotes retention of developed catchment N, transport limited
  Promotes export of forest catchment N – supply limited
  hydroclimate impacts reversed

Conceptual model shows moisture and nutrient flux within the ecosystem patch-hillslope scale for undeveloped and developed catchments



Geomorphology and infrastructure as controls of the spatial and temporal patterns of shallow soil moisture: locations of non-point N sources, hydrologic pathways

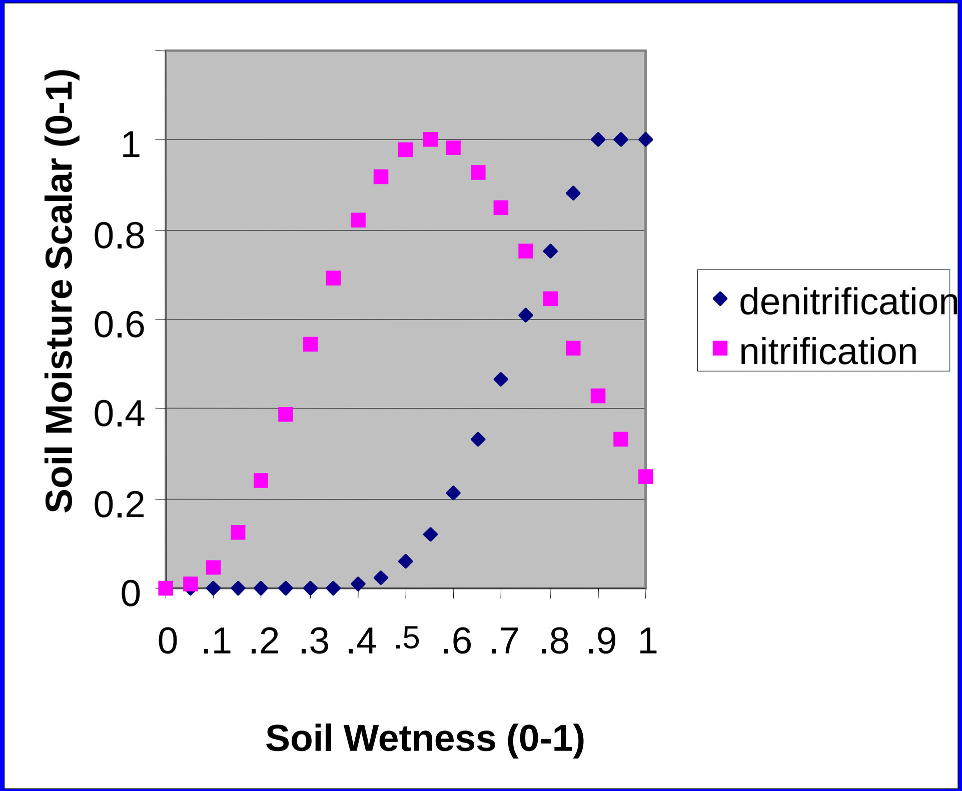
Baismans Run W3 Observed and Simulated NO3



Soil Moisture Controls on N-Cycling

Increased source by nitrification at mesic soil moisture,
increased sink at near saturated conditions

What are these patterns in the developed and undeveloped landscape?



$N_{nitrif} = f(H_20, NH_4, T, C/N, \ldots)$

$N_{denitrif} = f(H_20, C, T, NO_3, \ldots)$

other SM influences:
decomp, photosynthesis,
uptake, immobilization

(Century N-Gas Model, Parton et al., 1996)