Hydrological and Biological Controls of Aquatic N Removal in River Networks

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Take Home Message

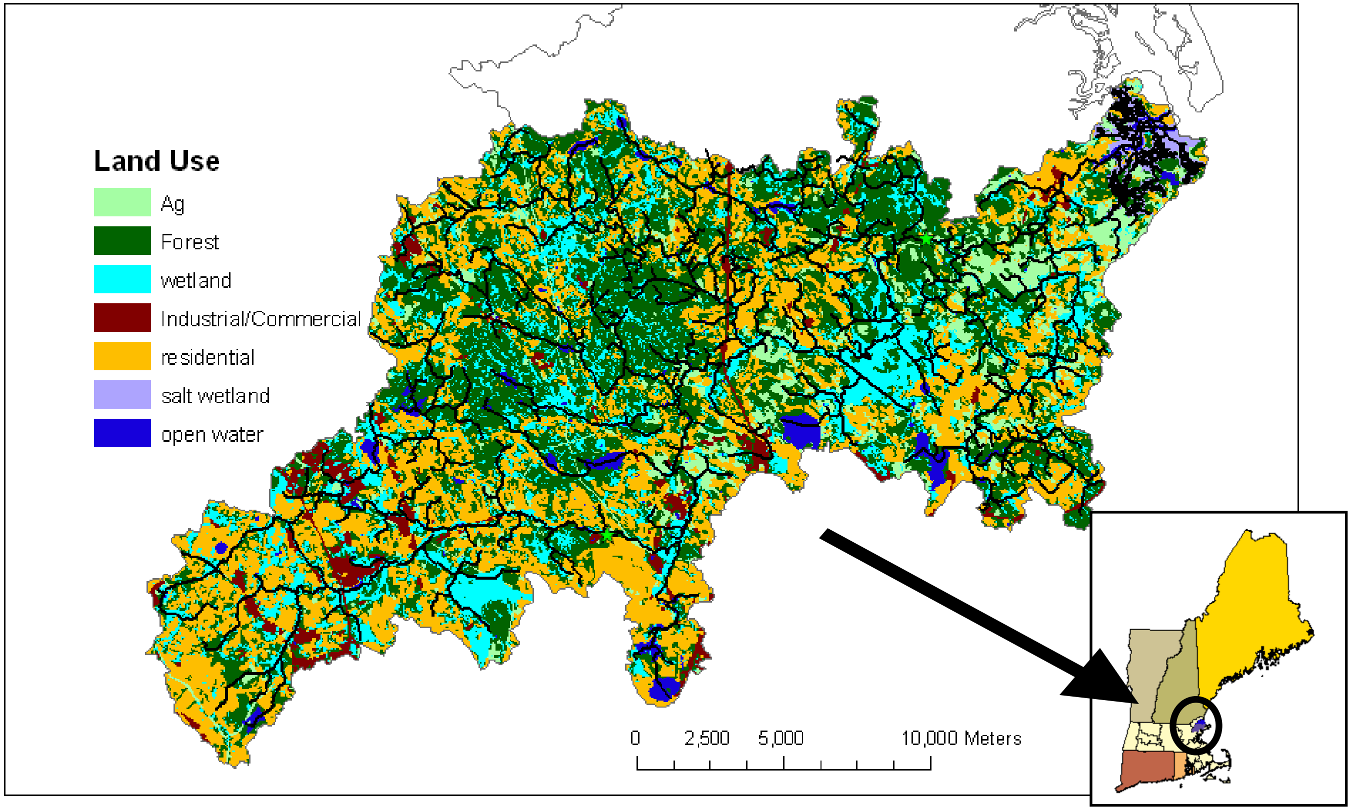
- River systems can effectively “treat” nitrogen pollution under base flow conditions
- But, this ability declines if nitrogen pollution levels increase too much
- River systems are less effective at treating nitrogen pollution at high flows (but this requires more research to fully assess)

Questions

- How effective are river networks at controlling nitrogen fluxes to the coastal zone in suburban basins?
- What limits their effectiveness?
- Are aquatic ecosystem services significant?

Land use - Suburban Basin

Ipswich R. Watershed, MA



Basin Area = 400 km^2

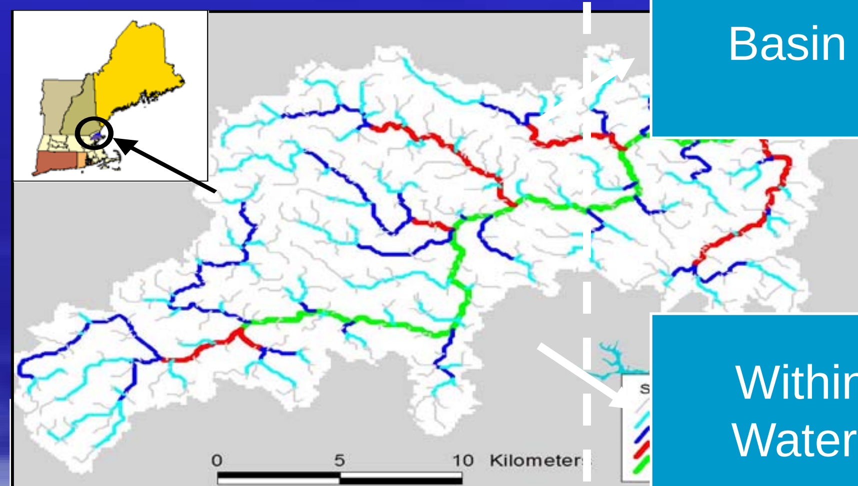
Conceptual Model

Climate Variability

Land use Change

Water/Waste Management

Network Model
(Ecosystem Services)



Inputs
Hydrologic
Hydraulic
Biological

Basin Exports

Within Basin Water Quality

Feedbacks

Biological and Hydrological Controls

Denitrification: the process whereby microbes use nitrate (NO_3) to oxidize carbon when oxygen is not available. Removes nitrate from the water to the atmosphere.

Biological Controls	Hydrological Controls
Nutrient concentrations (efficiency loss) Water temperature Supply of reactants (carbon, nitrate) Biological communities Oxygen Conditions	Width, depth of channels Lakes, reservoirs River network geomorphology (lengths) Floodplain connections Transient storage exchange and characteristics

↓ Affect microbial demand for nitrate

↓ Affect water depth and residence time (i.e. the likelihood that nitrate will encounter a denitrifying zone)

Mathematical Expression

- A simple equation for denitrification removal:

$$R = 1 – \exp(-\upsilon_f \ \tau/h)$$

υ_f = biological activity (length/time)

τ/h = residence time / water depth

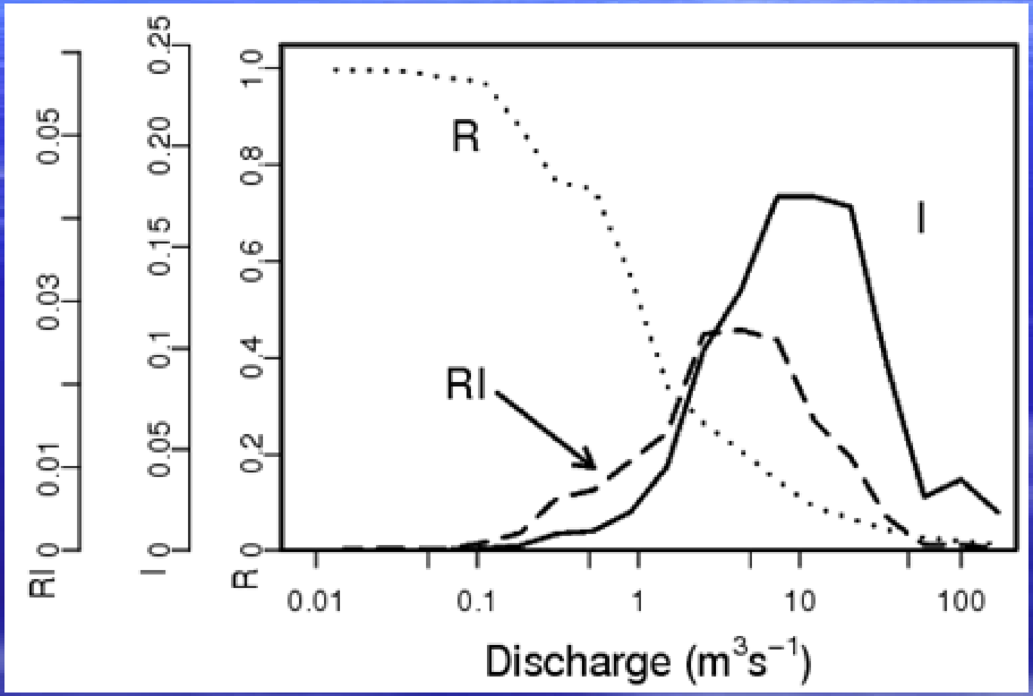
= hydrological conditions (time/length)

Components vary in space and time – need models to integrate

River Network Model

- Simple N removal model (denitrification)
- Gridded river network
- Nutrient loading – function of land use and runoff
- Hydrology
  - Specified runoff
  - Impervious effects
  - Mean hydraulics (downstream and at-a-site changes)
- Biological activity – non-linear (Mulholland et al. 2008)
- Considers channel network only
  - Transient storage implicit in reaction term.
- Daily time step

Biological control is reduced with increasing runoff conditions

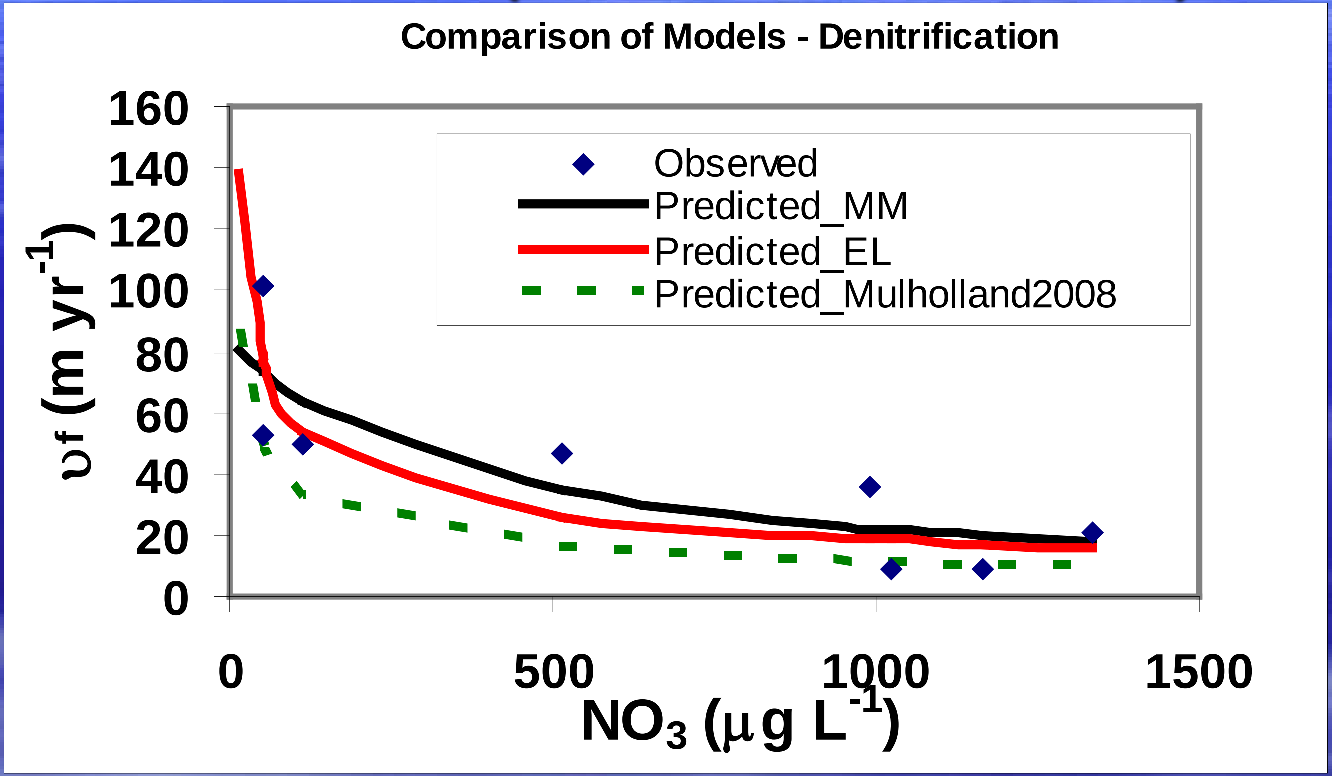


Using typical denitrification rates:

- River network effective at low flows (>40% removed)
- Not very effective at high flows (< 10% removed).
- Moderately effective over annual time scales (16 – 30%)

Wollheim et al. 2008. Dynamics of N removal over annual time periods.
JGR-Biogeosciences VOL. 113, G03038, doi:10.1029/2007JG000660

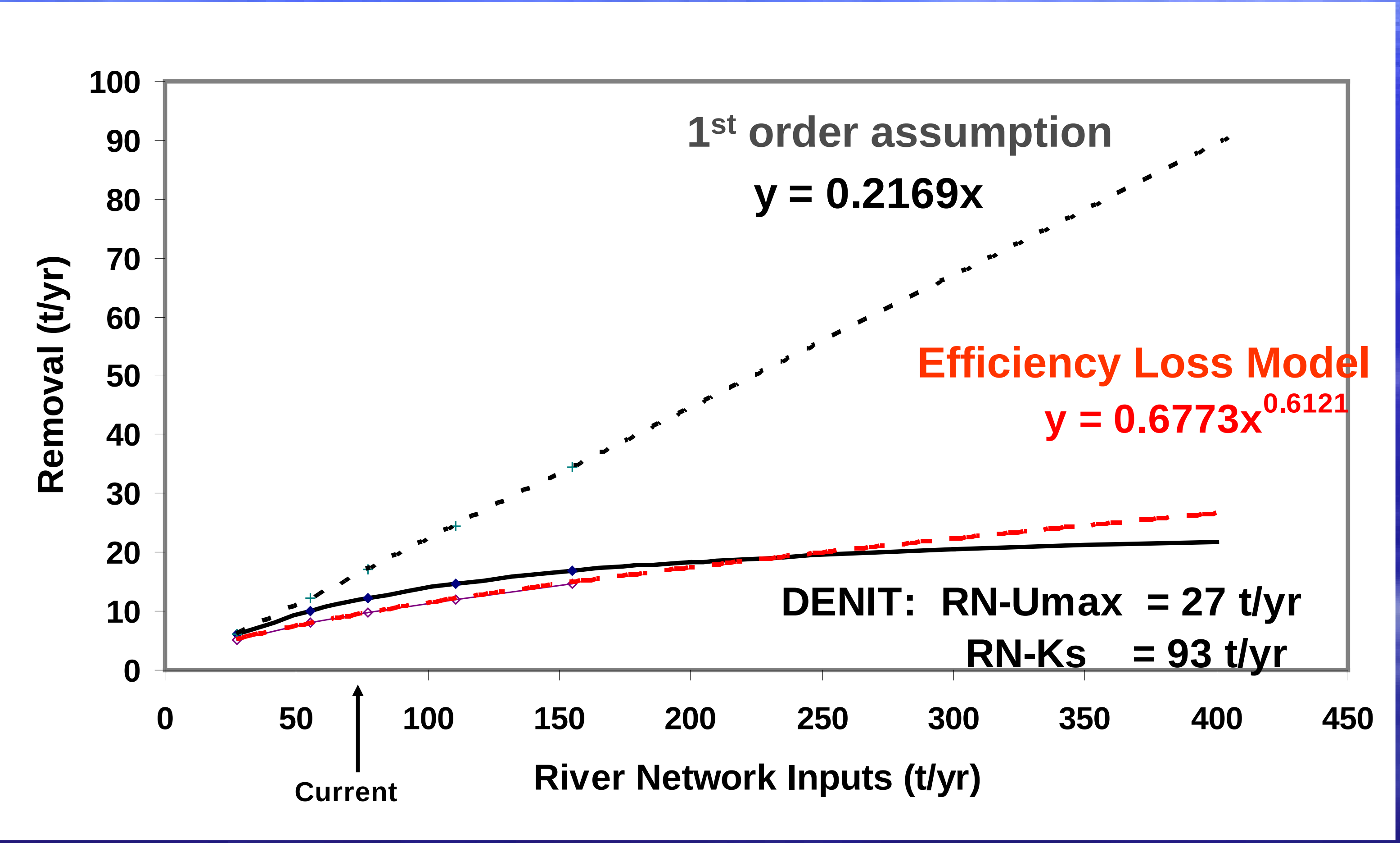
Biological Removal Processes Saturate (Denitrification)



In individual stream reaches, as nitrate concentrations increase, efficiency of N use declines

Peterson and Thomas, In Prep. PIE-LINX2

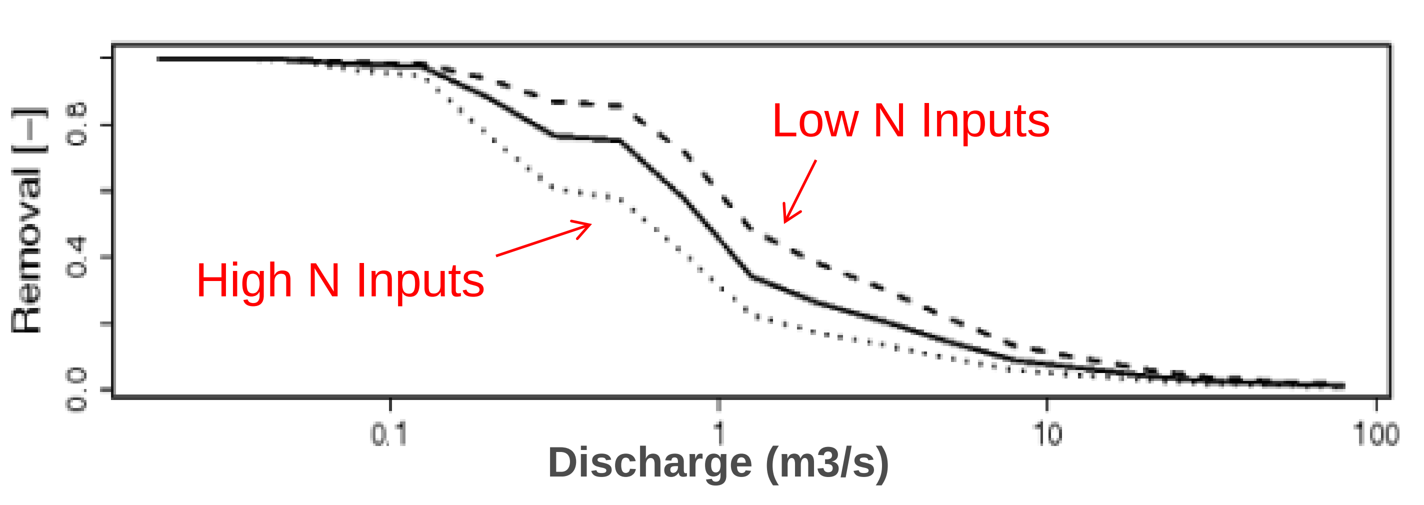
Biological Control is Reduced as N inputs increase



Exports will increase at faster rate than inputs.

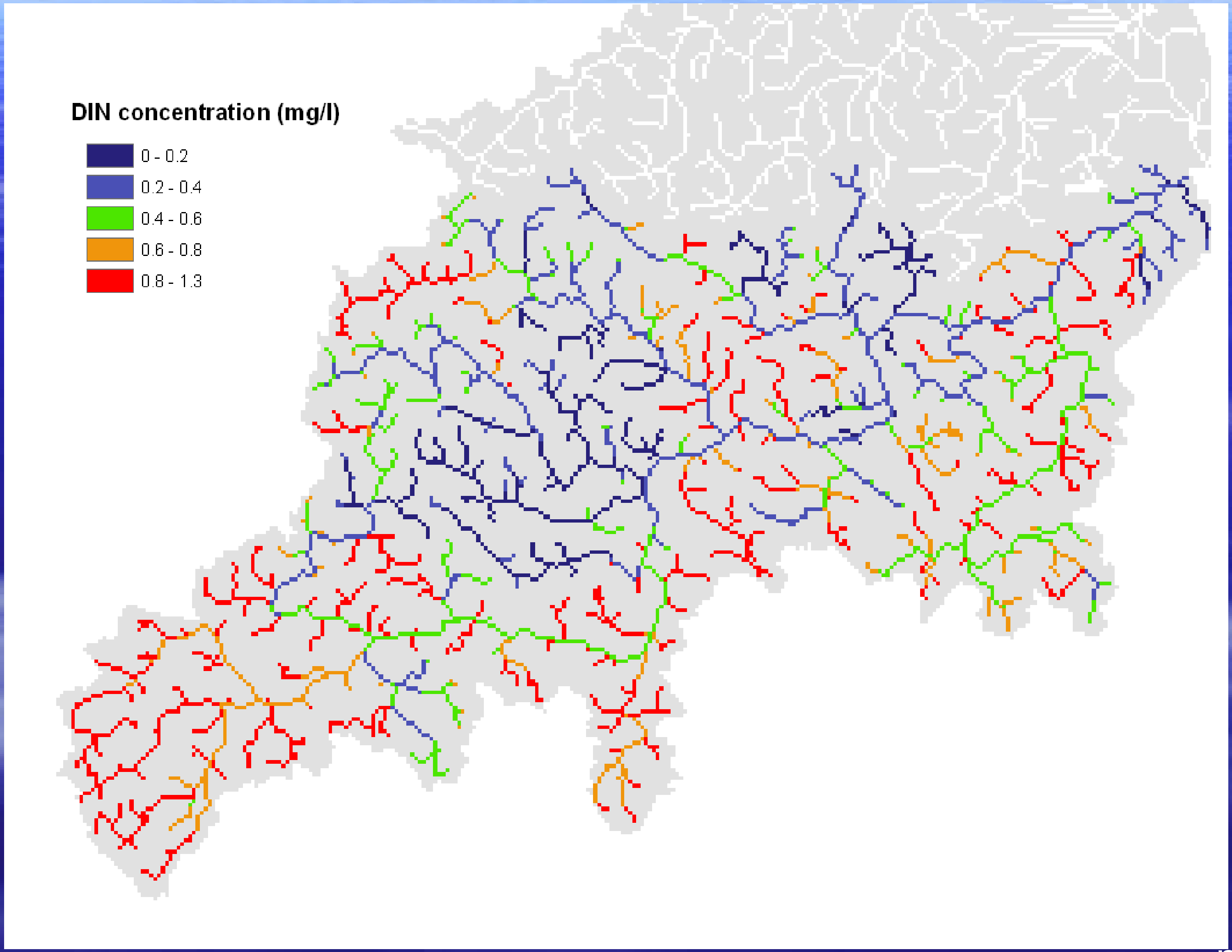
Biological control is most impacted during low to moderate flows

Three scenarios of differing N inputs



- Impact of increased loading is strongest near base flow.
- Hydrological conditions override this effect at high and low flows.

Concentrations Map – Low flow



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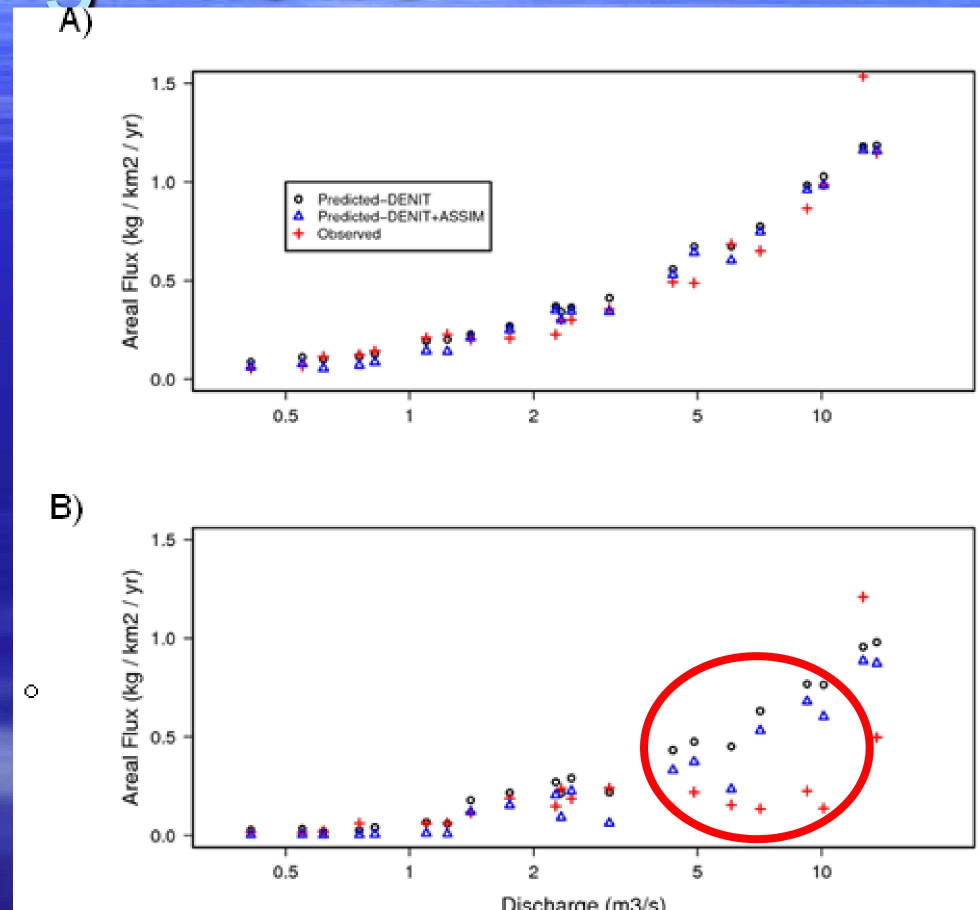
Model does not match observations at high flows

Headwater Fluxes

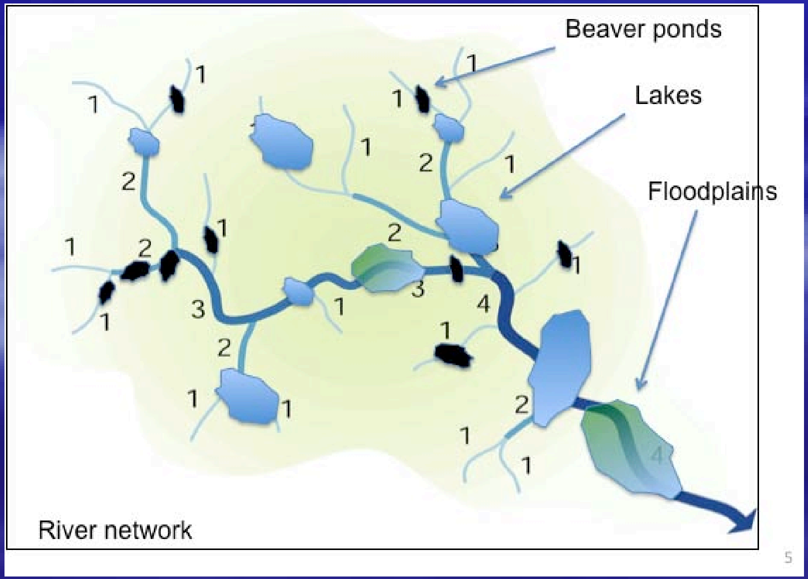
Basin Mouth Fluxes



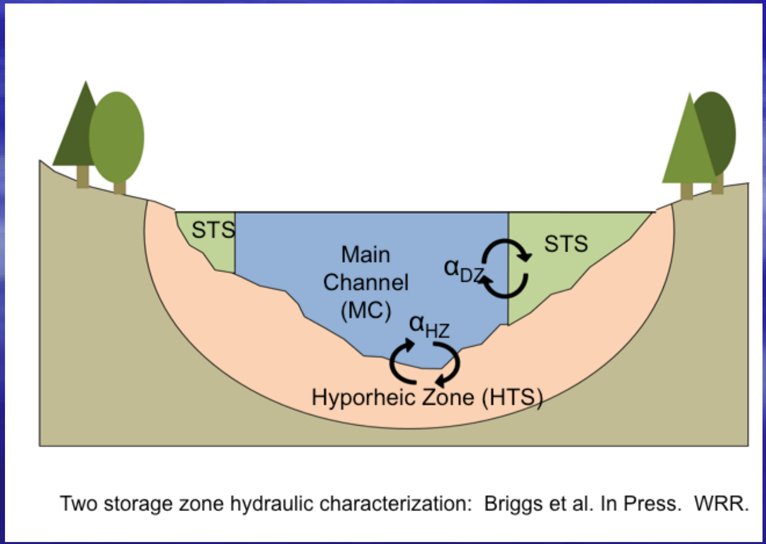
Enhanced Model

- Role of lakes, beaver ponds, floodplains
- Role of transient storage (see poster: R. Stewart)
  - – Surface transient storage
  - – Hyporheic transient storage

Hydraulic heterogeneity



Channel Cross Section



Conclusions

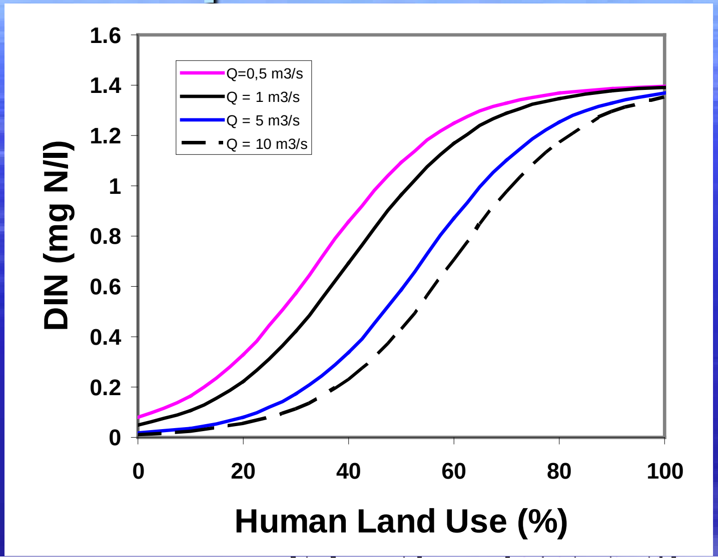
- River systems provide an important ecosystem service
  - are effective at removing nitrate from the water column, especially at low to moderate flows.
- Their effectiveness declines with increasing N inputs
- Their effectiveness declines with increasing flow.
- Effect of increasing N inputs is most strongly felt near baseflows
  - During period when estuarine residence times are longer

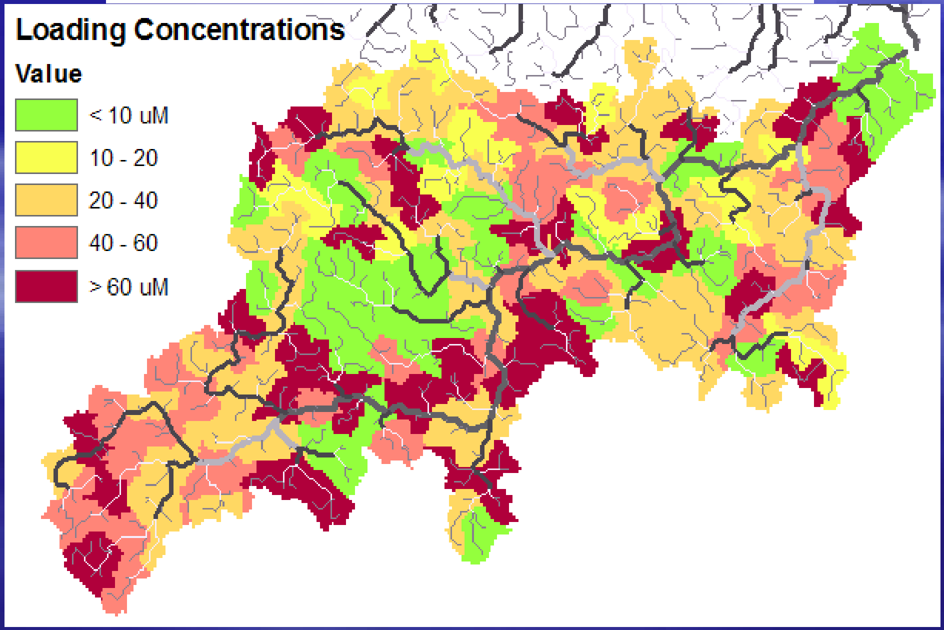
- But need to adequately account for heterogeneities and gradients in transient storage
  - (see Rob Stewart Poster for more)

QUESTIONS?

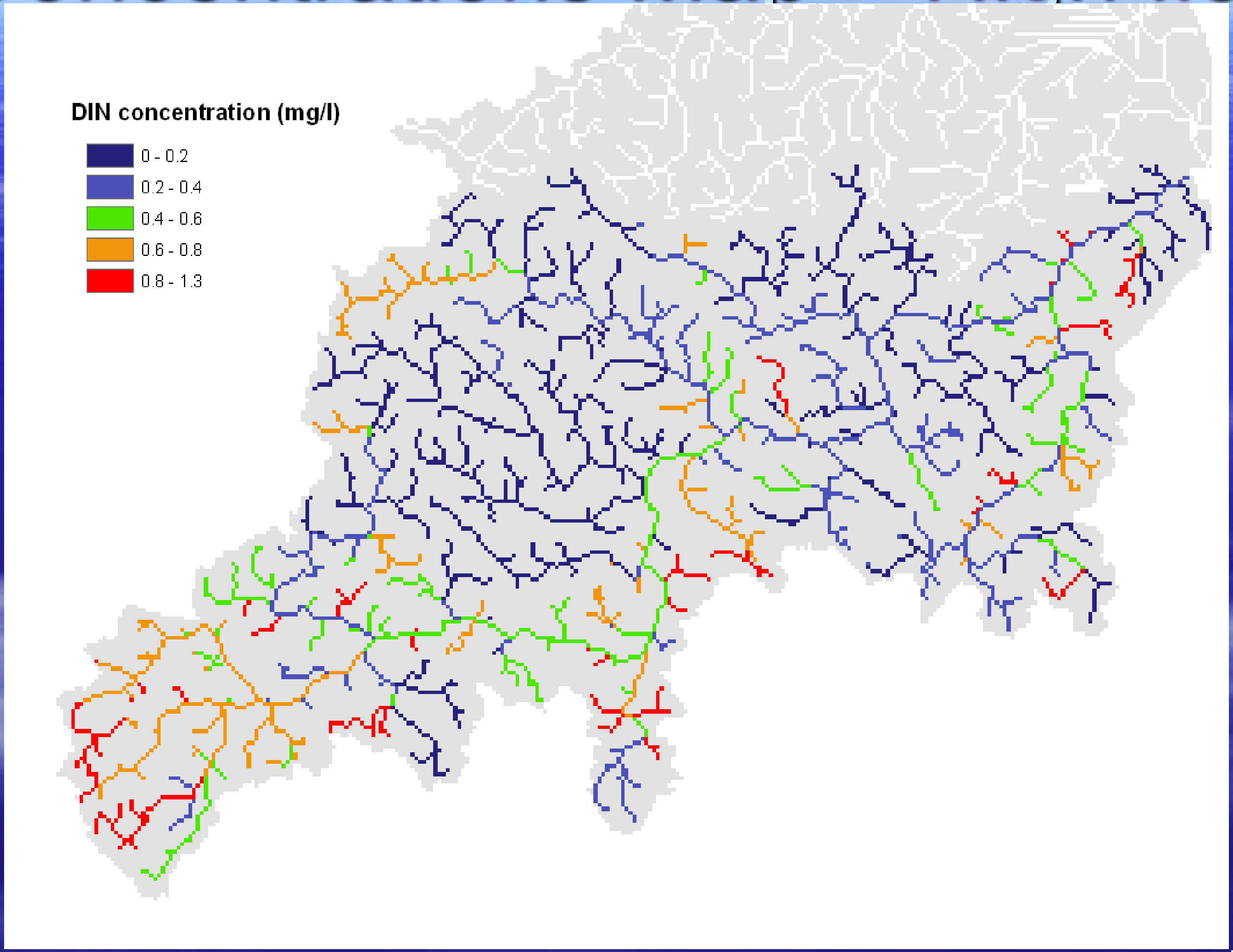
DIN Nonpoint Loading SubModel - Ipswich

Inputs to streams based on empirical model derived from headwater stream surveys conducted over a range of flow.





Concentrations Map – High flow



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