Present stream conditions and functional response to nutrient dynamics

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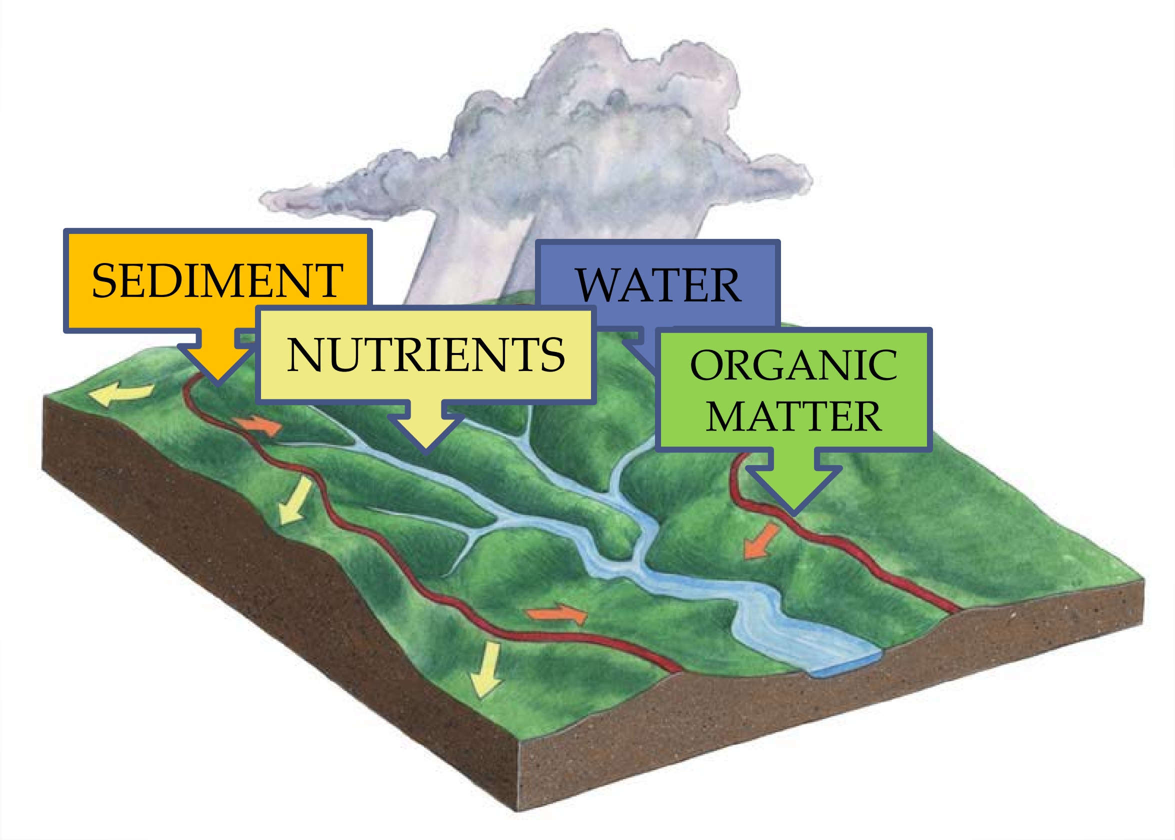
In every respect, the valley rules the stream.

H.B.N. Hynes (1975)

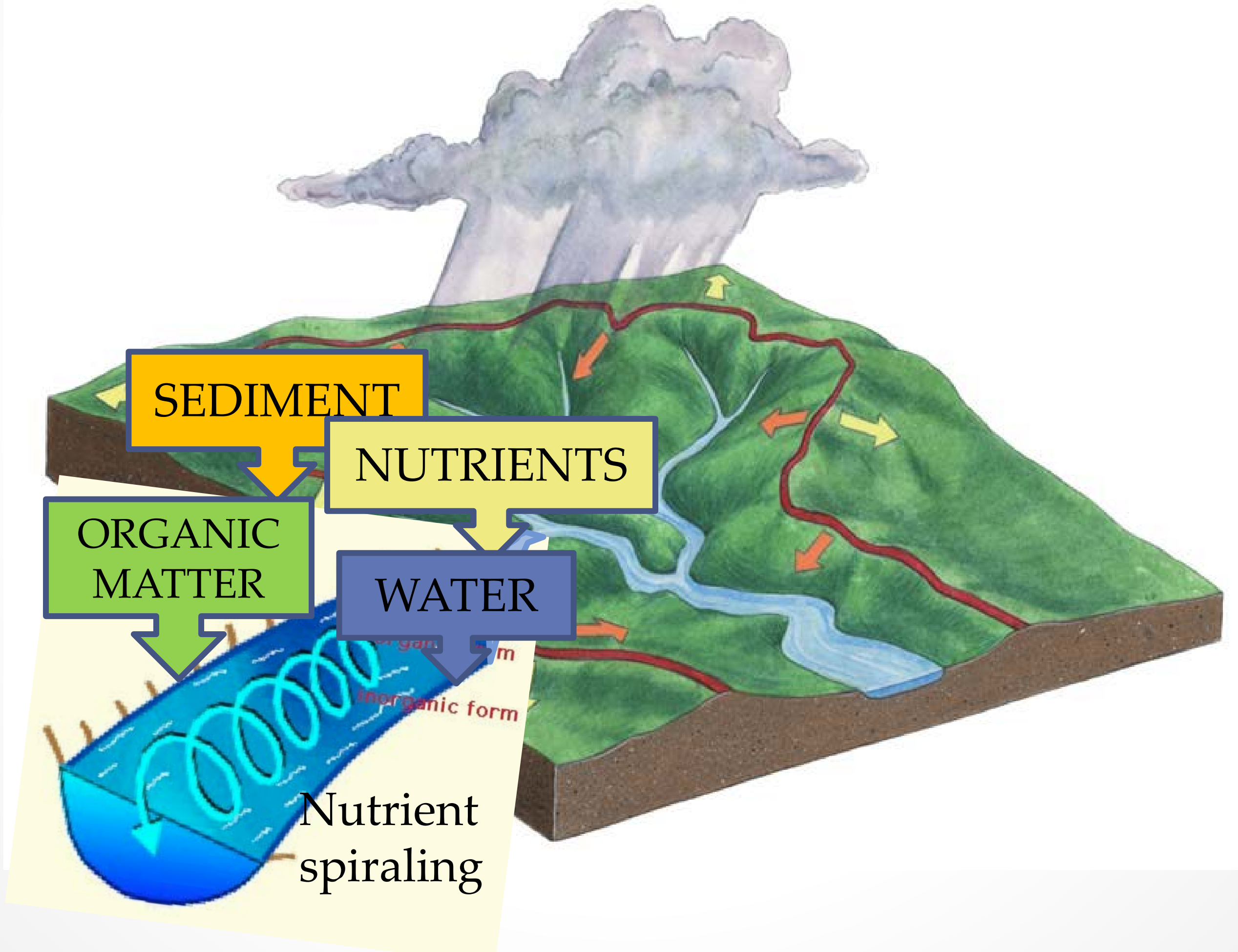
Topics

- Why the watershed controls nutrient processing function in streams
- Components and mechanisms of nutrient dynamics in stream channels and how they are affected by watershed conditions
- Focus on function of nitrogen removal via denitrification in streams; comparison of forested versus impacted streams

Watershed controls how much and how fast nutrients are loaded into streams



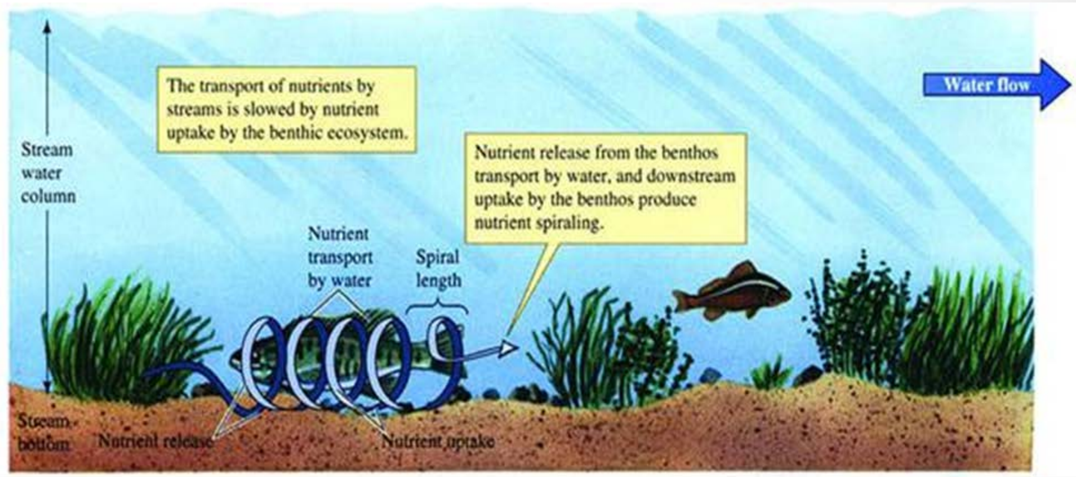
Watershed controls how fast water, nutrients and other materials move in streams



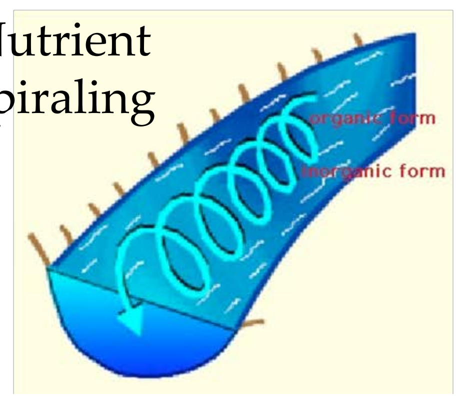
Nutrient cycling in streams

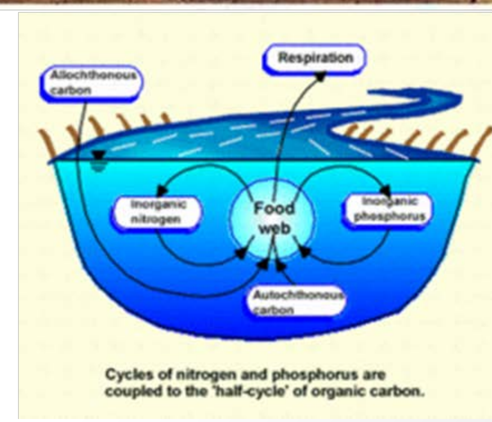
CONTROLS

- Nutrient supply
- hydrology
- geomorphology
- Energy source (OM)



Nutrient spiraling

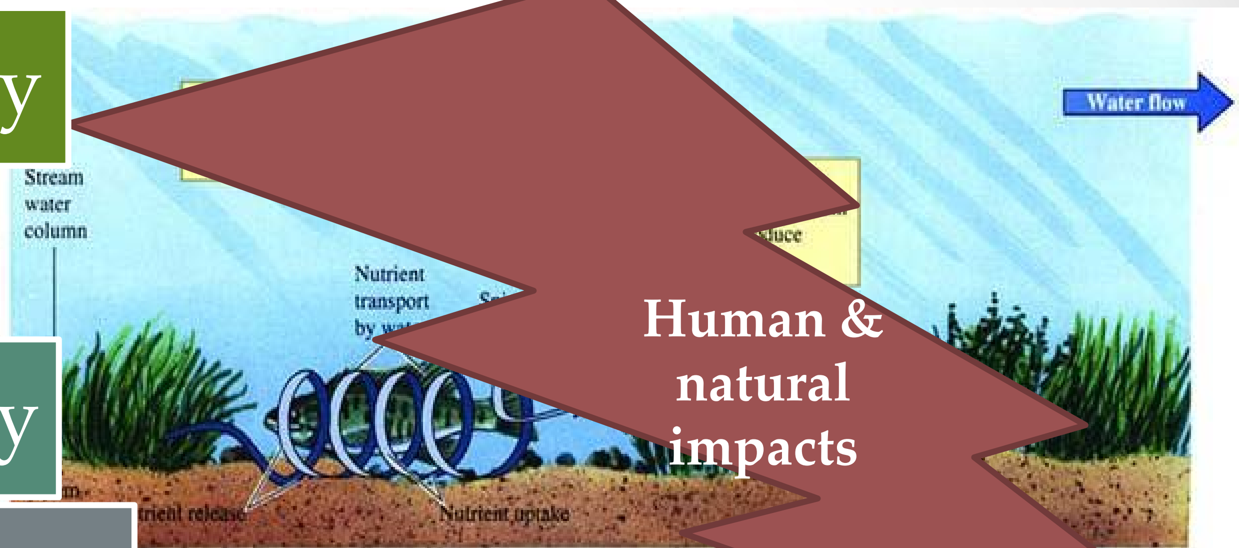


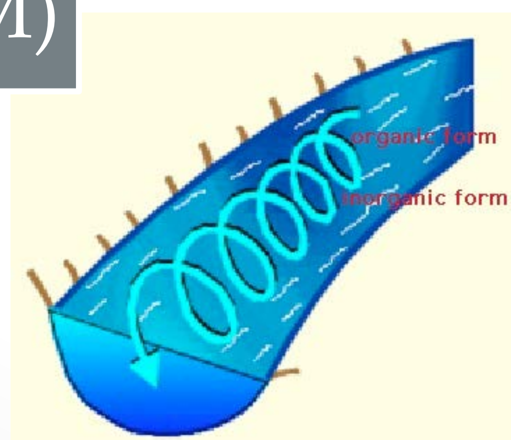


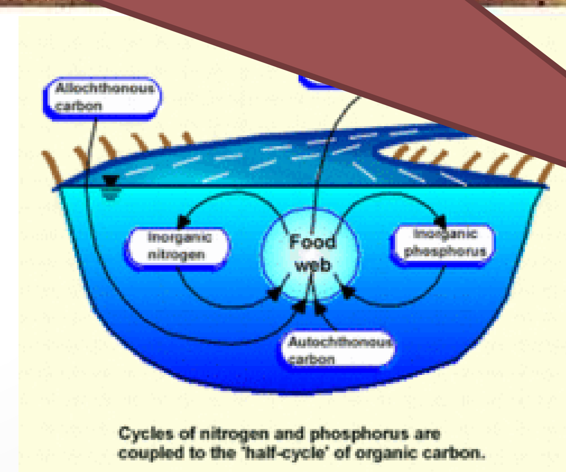
Controls of nutrient dynamics in streams

- Nutrient supply
- hydrology
- geomorphology
- Energy source (OM)

Human & natural impacts





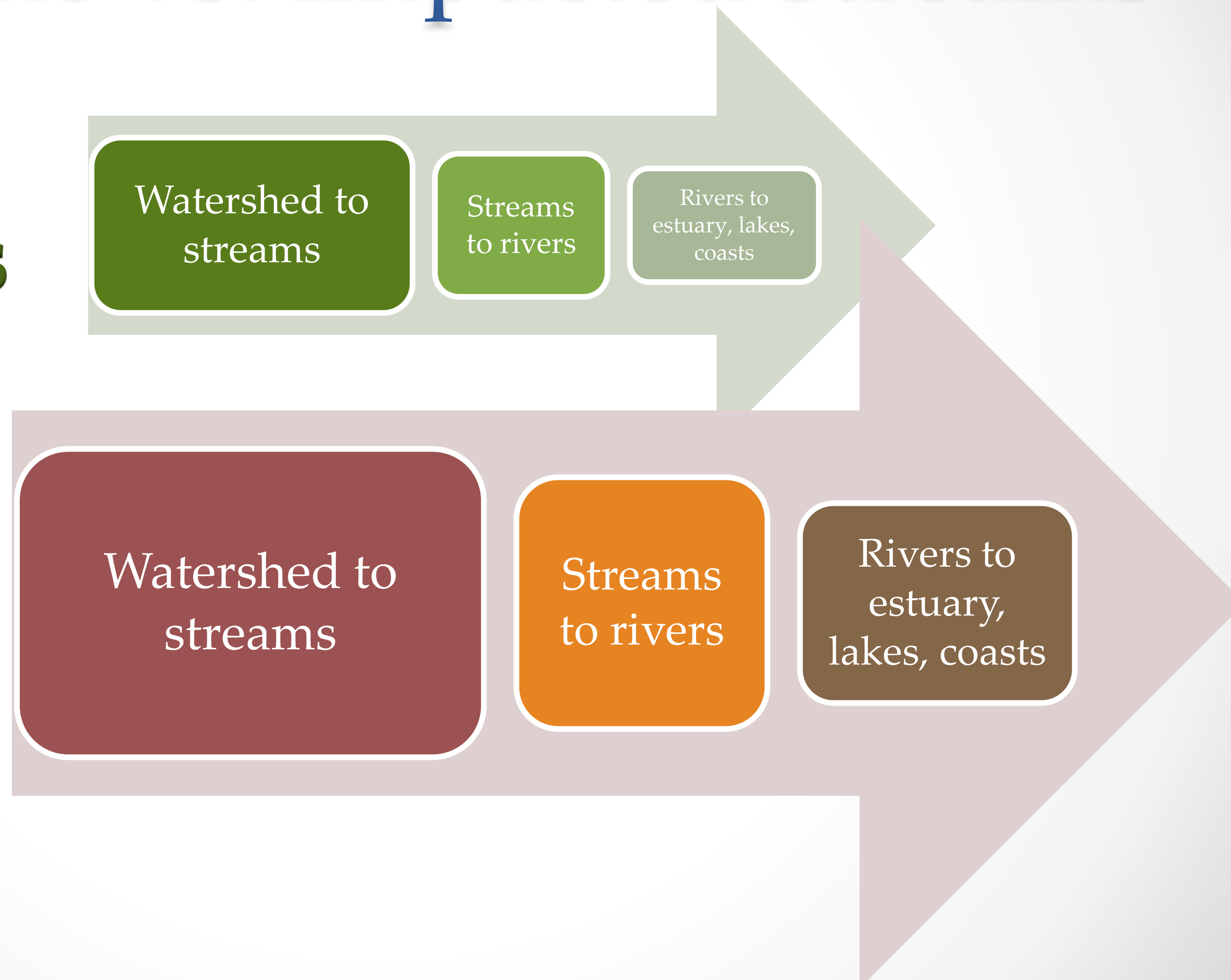


(Source: Biodiversity Institute of Ontario)

Comparison of Nutrient export in pristine vs. impacted streams

Pristine conditions

Human altered



Processes controlling in-stream nitrogen cycling

1. DIN removal processes
   - **to benthic substrate** (chemical precip, adsorption; to hyporheic zone, adsorption and microbial immobilization)
   - **to plants** (vascular plant uptake, periphyton uptake, plankton uptake)
   - **heterotrophic microbial immobilization**
   - **Complexation/adsorption with organic matter**
2. In-stream production of DIN
   - **Plant leaching** (vascular plants, periphyton and plankton)
   - **Heterotrophic microbial mineralization**
   - **Consumer excretion** (invertebrates and fish)
3. Losses
   - **downstream transport**
   - **Denitrification**
   - **Insect emergence**
   - **downstream migration to lakes, estuary and coasts**

Fundamental stream features that affect nutrient processing capacity

Healthy stream

- Nutrient limited (N in low order)
- Natural flow regime
- Healthy riparian vegetation
- Connected floodplain
- Hydrological exchange between stream and hyporheic zone
- Alloctonous OM
- Diverse benthic community
- Ecosystem respiration > GPP

Unhealthy stream

- Nutrient enriched
- Modified flow regime
- Degraded/lack of riparian veg.
- Incised channel
- No hydrological exchange between stream and hyporheic zone
- Autoctonous OM
- Impaired benthic community
- Increased GPP

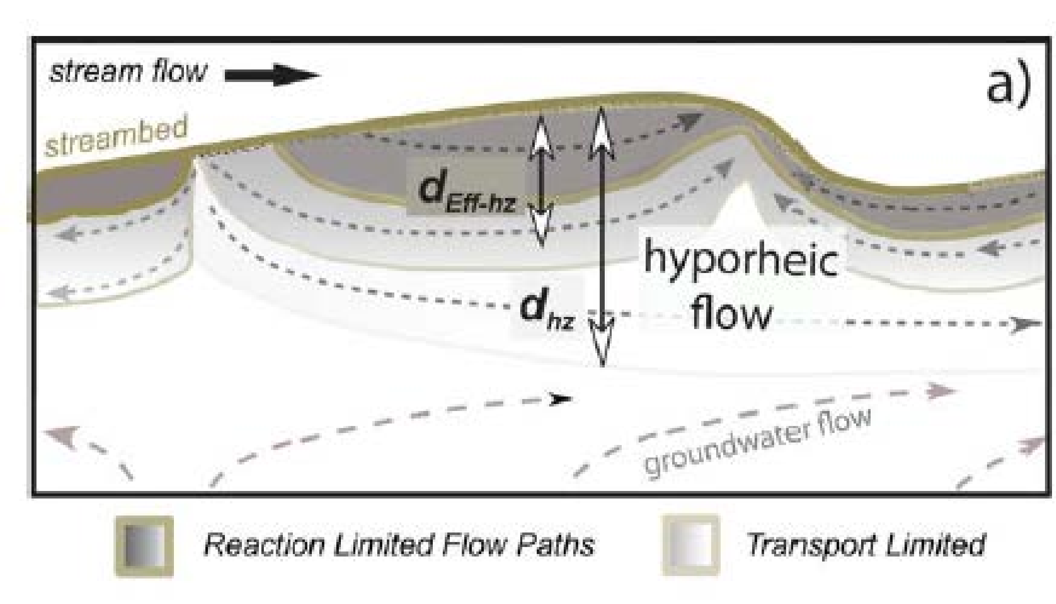
Why do streams lose their capacity to retain nutrients?

- When N and P concentrations are high, temporary biotic uptake increase but permanent N loss via denitrification decrease (competition for resources)
- When riparian forest is degraded or non-existent, ecosystem respiration rates decrease and reduce chances for denitrification; nutrient uptake and retention by microbes decrease
- When light incidence is relatively high, GPP and production of labile organic matter increase; microbial immobilization and denitrification decrease
- Hydrologic disturbances decrease accumulation of OM
  - Export nutrients faster than they may be utilized biologically
  - Impact benthic communities
- Unstable/simplified channel/channel incision
  - Fewer "compartments" for nutrient uptake and storage
  - Less opportunity for nutrient uptake and recycling
  - Loss of hyporheic zone and effective zone of significant denitrification
  - Export of particulate matter and sediment with P

Focusing on denitrification

- In-channel denitirification generally accounts for a small portion of nitrate uptake (avg 16%) in streams.
- Denitrification rates decrease with **discharge** and **ammonium** concentrations
- Rates increase with nitrate concentrations, OM, and ecosystem respiration.
- Denitrification rates increase with nitrate concentrations but efficiency decreases, reducing the proportion of in-stream nitrate that is permanently removed in stream flow.
- Much of the denitrification in channel occur in the effective hyporheic zone (can remove up to 10% of the nitrate in a channel reach).

Not all hyporheic zone denitrifies



- Rates in hyporheic zone vary widely.
- Not dominant in a single geomorphic unit.
- Limited by reactive sites or by nitrate-rich water exchange.

N concentrations in MD streams are high

	TN (mg/L) (Nitrate ~ 70%)	over 1.38-1.68 mg/L TN	Source
Mid Atlantic CP	0.93, 2.50	***	Morgan et al. 2013
NE Piedmont	1.60, 1.80	**	Morgan et al. 2013
SE Plains	0.33, 0.82		Morgan et al. 2013
Forested stream ex.	0.15 mg/L of nitrate 0.50 mg/L TN	-	Groffman et al. 2004
Agricultural stream ex.	4 mg/L of nitrate	****	Groffman et al. 2004
Suburban stream ex.	2 mg/L of nitrate	****	Groffman et al. 2004
MD First order streams	1.27		Morgan & Kline 2011
MD Second order streams	1.47	*	Morgan & Kline 2011
MD Third order streams	1.24		Morgan & Kline 2011

N status in MD streams

	TN (mg/L)	over 1.38-1.68 mg/L	Source
Mid Atlantic CP	0.93, 2.50	***	Morgan et al. 2013
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criterion. To protect small stream integrity in Maryland, we recommend an upper stream TN criterion between 1.34 and 1.68 mg/L and an upper stream TP criterion between 0.025 and 0.037 mg/L, based on quantile analyses. Elevated

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Nutrient concentrations in Maryland non-tidal streams

Raymond P. Morgan II · Kathleen M. Kline

Estimating N removal in small catchments of the Chesapeake Bay watershed

Table 3. Inputs, Outputs and Retention of N for Suburban (Glyndon), Forested (Pond Branch) and Agricultural (McDonogh) watersheds

	Suburban	Forested	Agriculture
	(kg N ha^{-1} y^{-1})		
Inputs			
Atmosphere[1]	11.2	11.2	11.2
Fertilizer[2]	14.4	0	60
Total	25.6	11.2	71.2
Outputs			
Streamflow[3]	6.5	0.52	16.4
Retention			
Mass	19.1	10.7	54.8
Percent	75	95	77

Groffman et al. 2003

Ecosystems (2004) 7: 393–403

- Estimated N removal from denitrification in a 200-m stream reach
  - o Forested = 0.05 to 5 kg N/yr
  - o Agricult. = 1.00 to 18 kg N/yr
  - o Suburb. = 0.50 to 15 kg N/yr

RATES FROM MULHOLLAND ET AL. 2008

Visualizing magnitude of N removal from denitrification in streams

	Total N input to catchment (kg N/yr)	Export in stream (kg N/yr)	Removal from denit. in 200-m reach LOW – HIGH (kg N/yr)	% removal in stream reach
Forested	560	26	0.05 to 5	0.20 to 20
Agricultural	3,560	820	1.00 to 18	0.12 to 2.2
Suburban	1,280	325	0.50 to 15	0.15 to 4.6

- Using N input rates from Groffman et al. (2004)
- Assuming drainage area of 50 ha

Conclusions

- The capacity of streams to process and remove nutrients from stream flow is directly controlled by nutrient supply, stream geomorphology, hydrological regime, and organic matter availability.
- Difficult to de-couple controls from watershed, especially from the magnitude of nutrient supply.
- High nutrient concentrations in streams have a negative effect on processes that remove nutrients permanently.
- Concentrations of nutrients in streams in some parts of MD, for ex. are above recommended levels. Therefore, even if we are able to increase denitrification capacity in stream reaches, reduction achieved not likely to show significant effect on concentrations.
- The capacity of streams in the Chesapeake Bay at processing nutrients is limited by high nutrient inputs from the watershed in addition to hydrological disturbances and changes in subsidies that sustain key processes.

Thanks!