Nutrient Attenuation in streams and rivers in the Puget Sound watershed

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Nutrient Advisory meeting – Aug 2018

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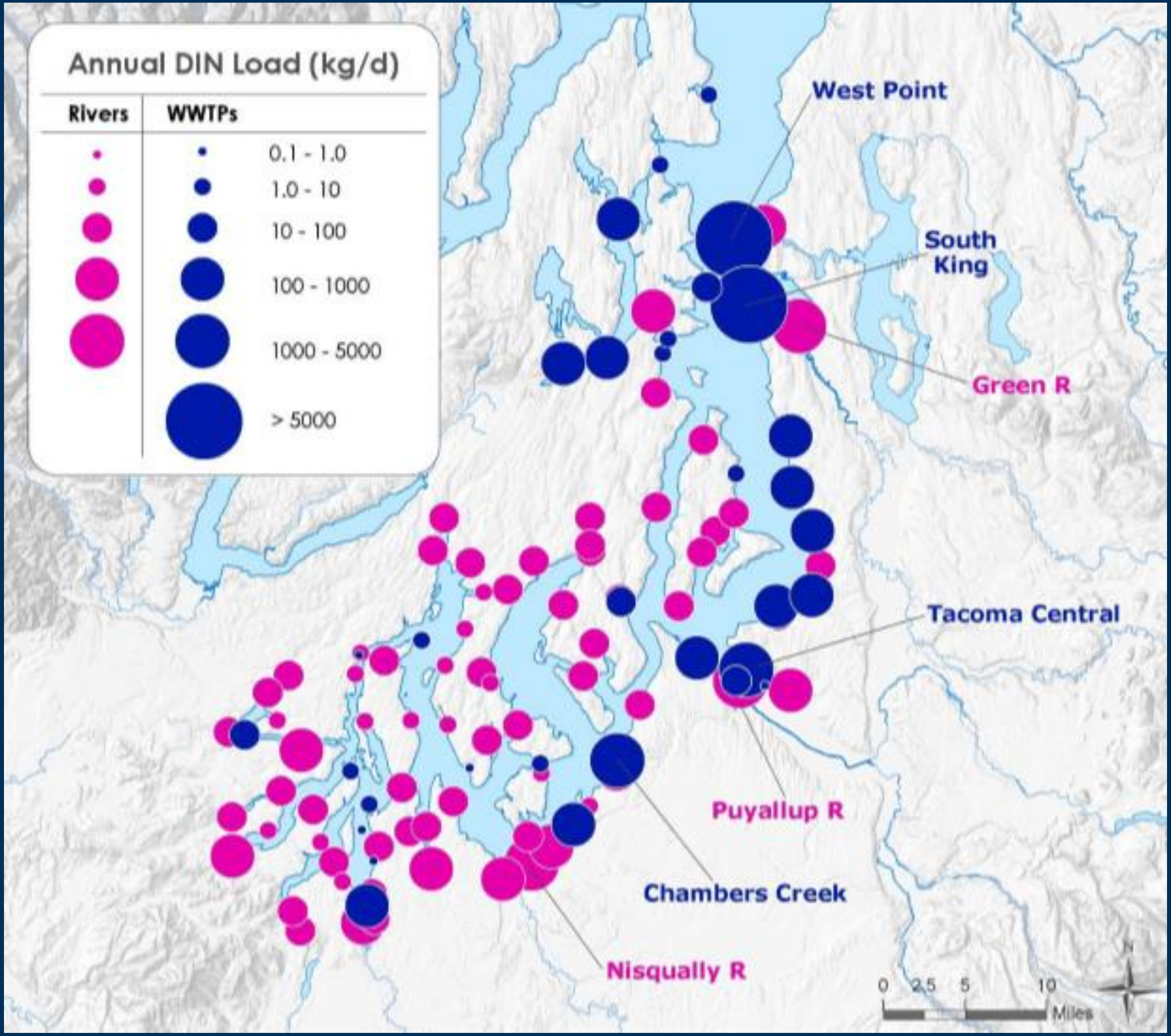
Background

- Issue - Portions of South Puget Sound have dissolved oxygen (DO) levels that fall below Washington State water quality criteria.
- One cause of these conditions is excess nutrients which can promote algal growth.
- A big source of nutrients to Puget Sound is the marine waters that enter through the Strait of Juan de Fuca
- However, freshwater sources can contribute to the problem

Nutrient Loading from rivers and WWTPs



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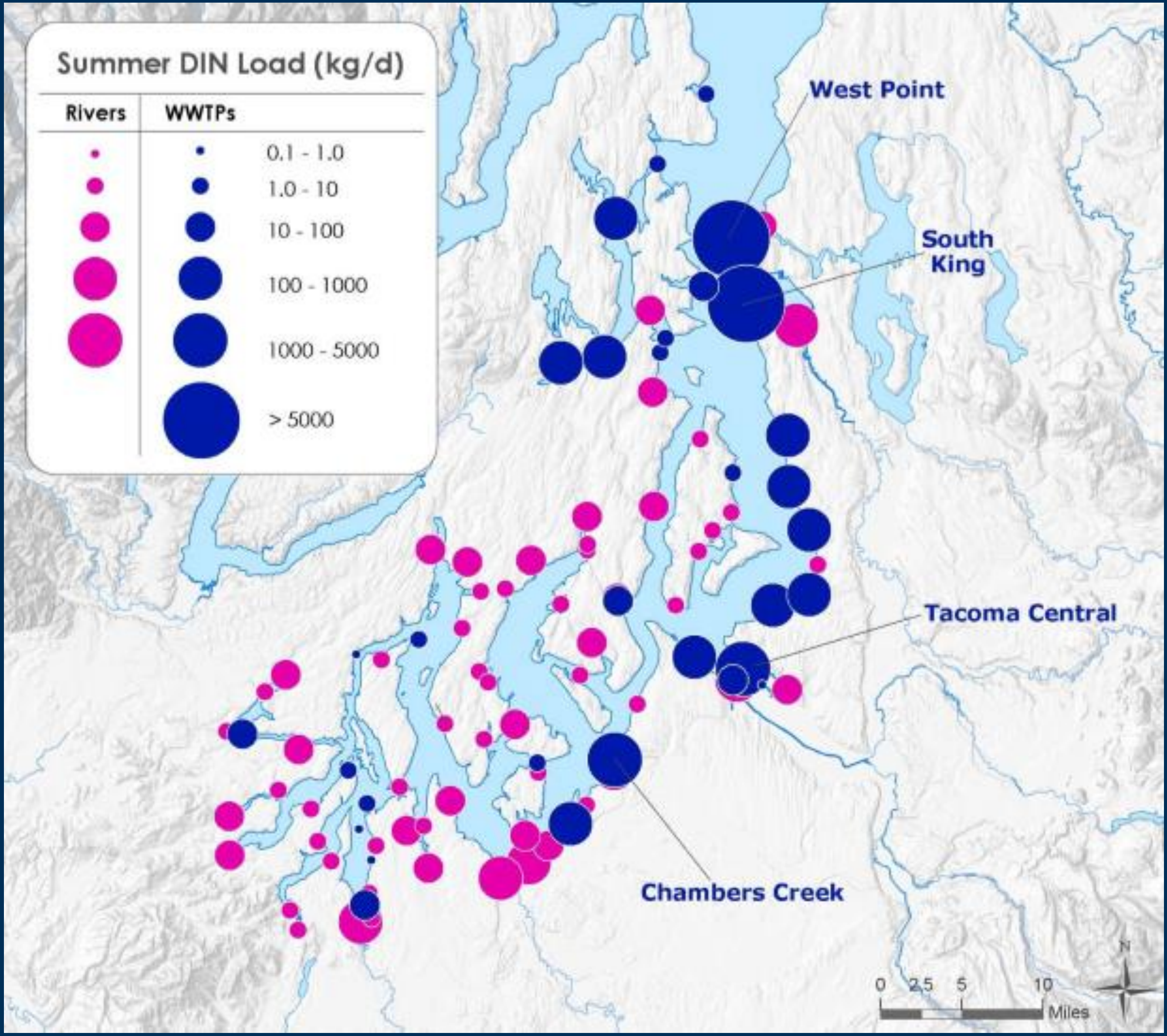
Mohamedali et al, 2011

Nutrient Loading from rivers and WWTPs



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Mohamedali et al, 2011

So, what can we do to reduce freshwater loads?

- Fortunately, nutrients are not conservative, they are biologically active and can be transformed and reduced during transport in surface waters
- Therefore, we can:
  - design WWTPs to enhance reduction of nutrients
  - design stream and river restoration projects to include consideration of nutrient processing.

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Nutrient attenuation project

- Goal: Determine what factors are important for nutrient attenuation in stream and rivers
  - Attenuation – a reduction in surface water nutrient load
- Conducted a literature review to identify
  - Conditions that lead to nutrient attenuation
  - What models are used to estimate nutrient attenuation in streams and rivers
- Applied a simple model to Puget Sound rivers and streams to identify high and low areas for attenuation

Nutrient attenuation project

- We developed a ‘score card’ to help identify what stream and river reaches will lead to enhanced attenuation.
- We focused on dissolved nutrients (nitrate+nitrite, ammonium, orthophosphate)
- These forms are readily taken up by algae and plants
- Focus today will be on nitrogen

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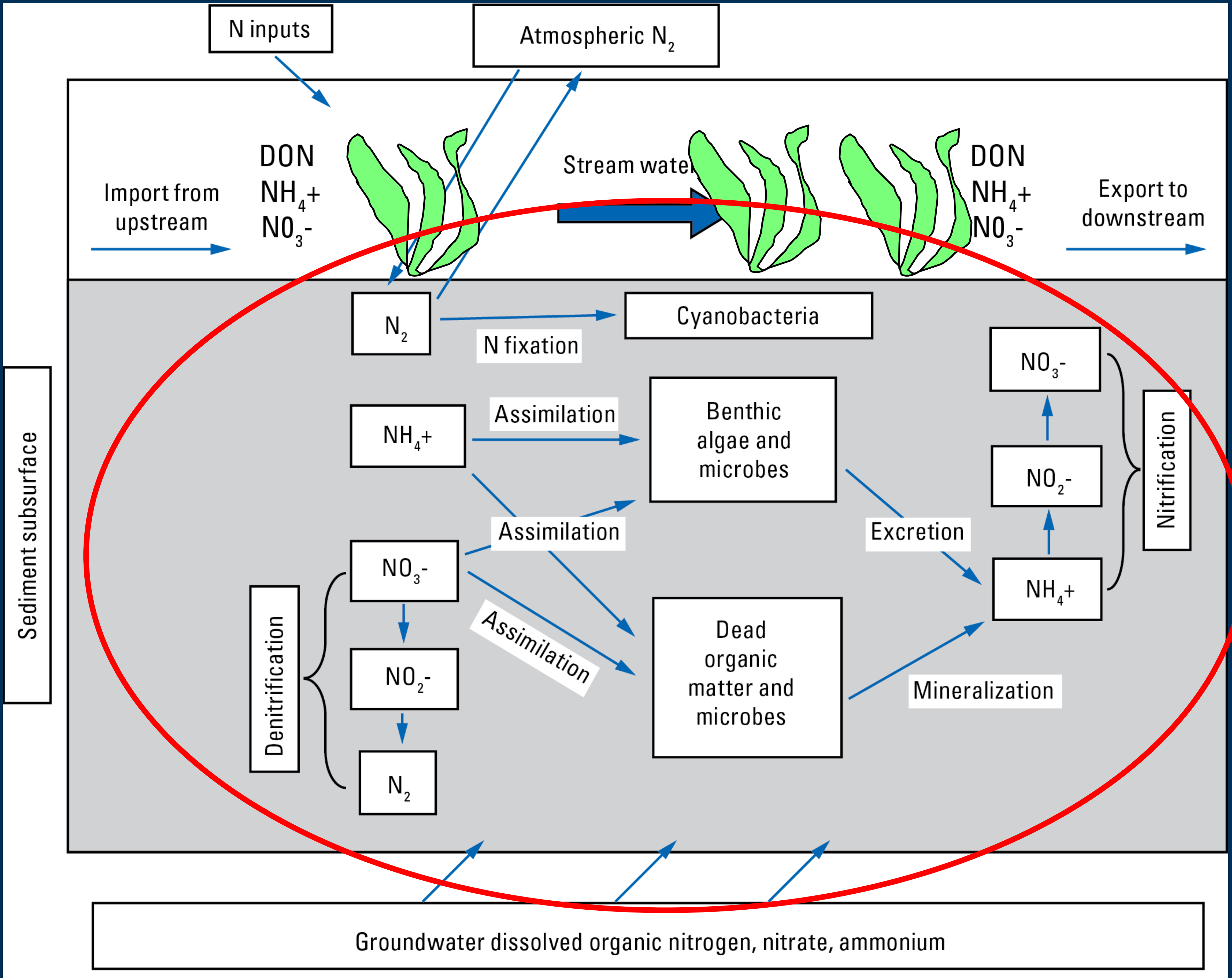
Factors related to nutrient attenuation

- There are physical, chemical, and biological factors that relate to enhanced attenuation of nutrients
- Often they interact with each other



N inputs
Atmospheric N_2
Import from upstream
DON
NH_4+
NO_3-
Stream water
DON
NH_4+
NO_3-
Export to downstream
Sediment subsurface
N_2
N fixation
Cyanobacteria
NH_4+
Assimilation
Benthic algae and microbes
NO_3-
NO_2-
NH_4+
Nitrification
Assimilation
Excretion
NO_3-
Assimilation
Denitrification
NO_2-
N_2
Dead organic matter and microbes
Mineralization
Groundwater dissolved organic nitrogen, nitrate, ammonium

Physical Factors

- Key question: How do we get nutrients into the sediment to be processed?
  - Overarching theme in the literature is if we can increase travel times through a reach, we can increase our chances of nutrient attenuation.
  - Contact time between surface water and sediments

Physical Factors

- Stream flow
  - Higher flows will have shorter travel times
- Velocity, width, and depth all interact and will influence travel times through the reach
- Channel geometry
  - Wide shallow channels vs. narrow deep channels - width to depth ratio of the channel
  - Influences the proportion of surface water in contact with sediments

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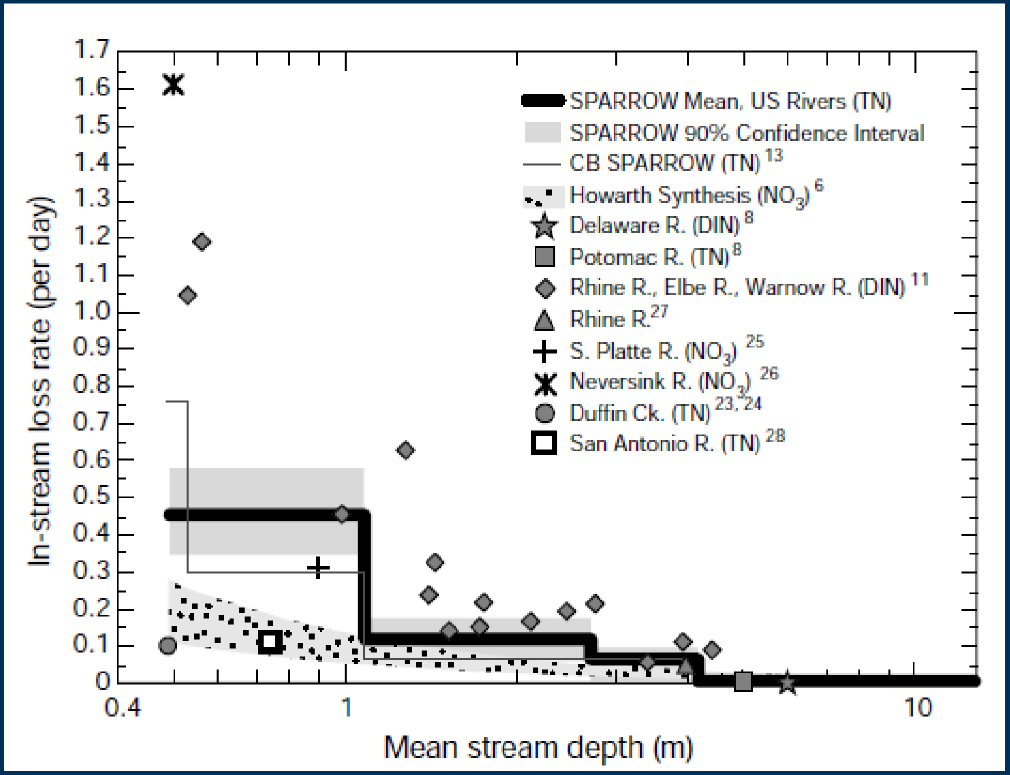
Physical Factors –stream order

- **Lower order streams tend to be better at processing then higher order**
  - **Many more 1st order streams in river networks then larger order streams**
  - **More water contact with streambed**



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Alexander et. al, 2000

Physical Factors –floodplain connectivity

- A river that can interact with its floodplain the more opportunity for flood waters to reach areas of shallow topography and increased travel times
  - Denitrification rates higher in floodplain soils
  - Storm flows often carry high percent of annual nutrient loads
  - Channel confinement ratio, floodplain width to channel width (>3 unconfined)

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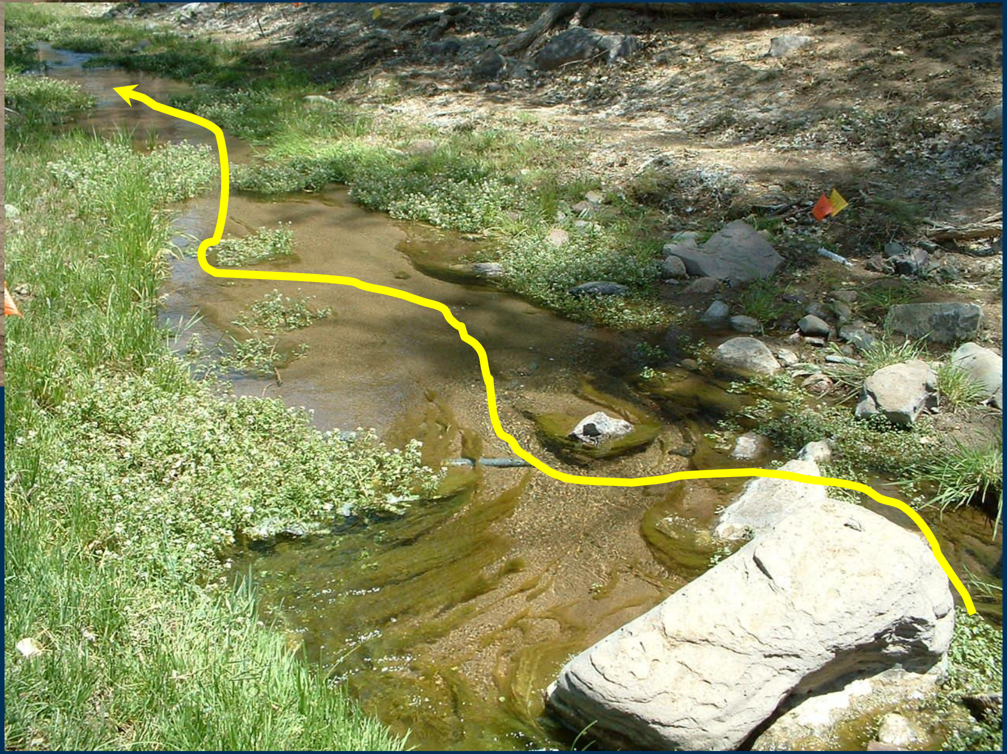
Physical Factors – channel complexity



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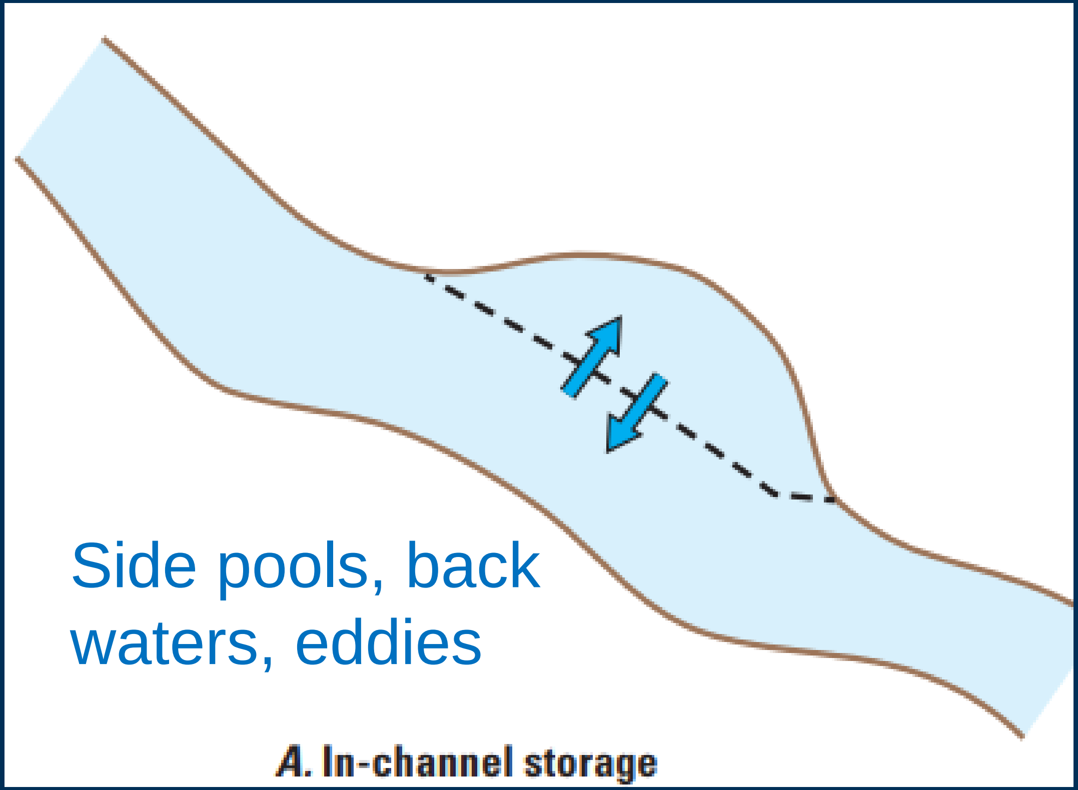
Physical Factors – Surface storage



Physical Factors – GW/SW exchange

- Hyporheic Zone – area where groundwater and stream water exchange/mix
- Transient Storage – in channel storage and hyporheic storage
  - Features that slow down the bulk flow of surface water

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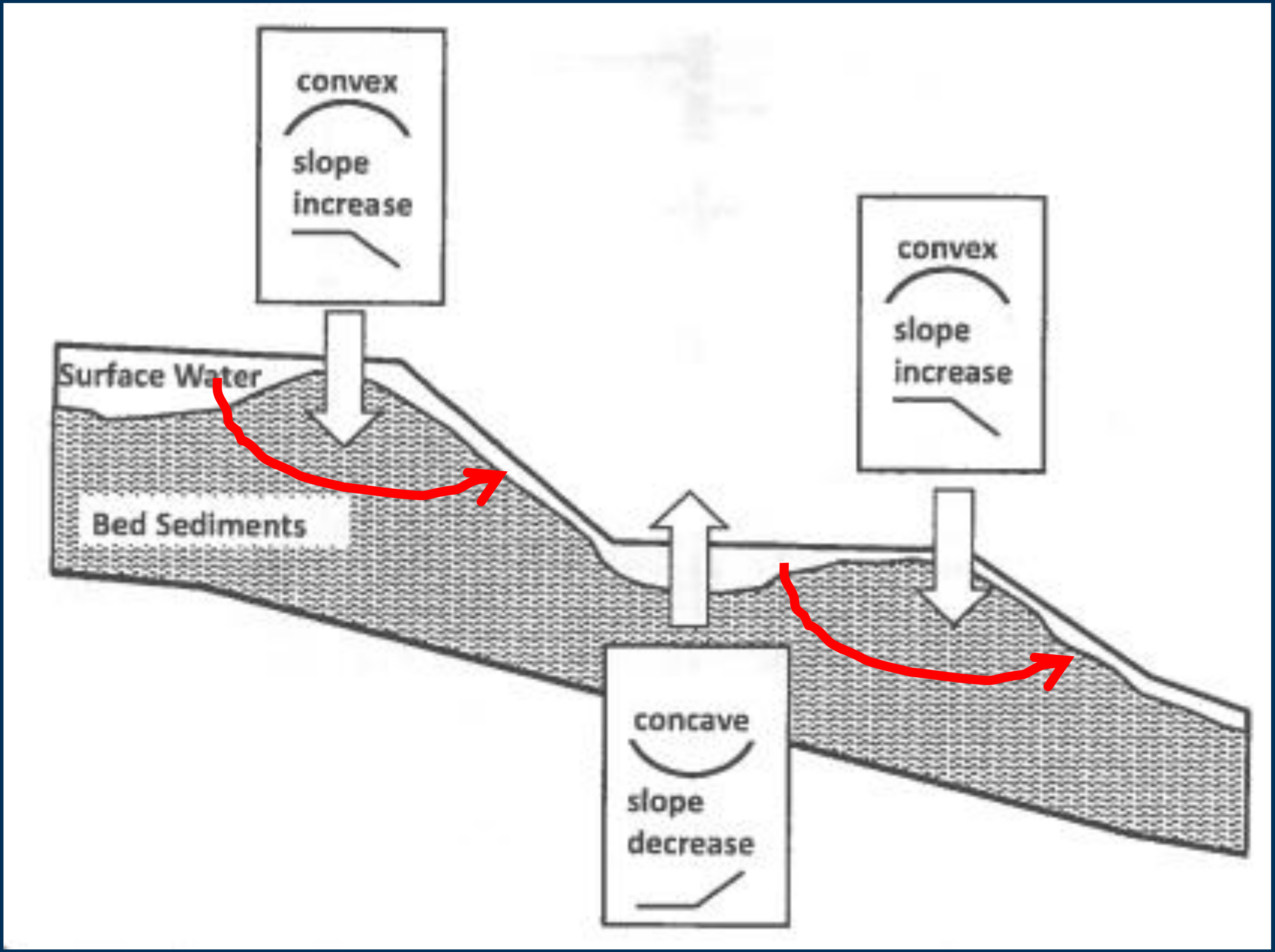
Physical Factors – GW/SW exchange



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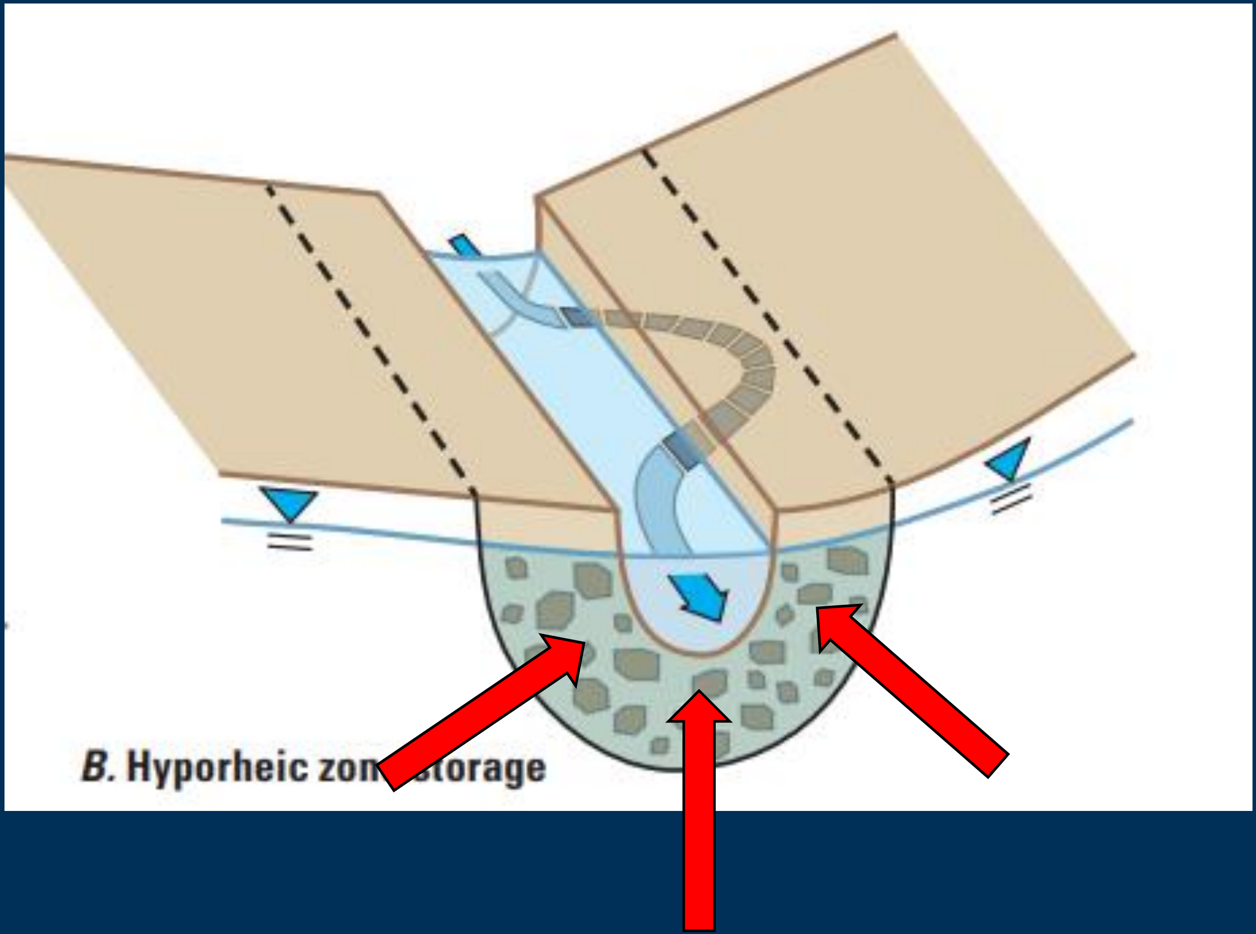
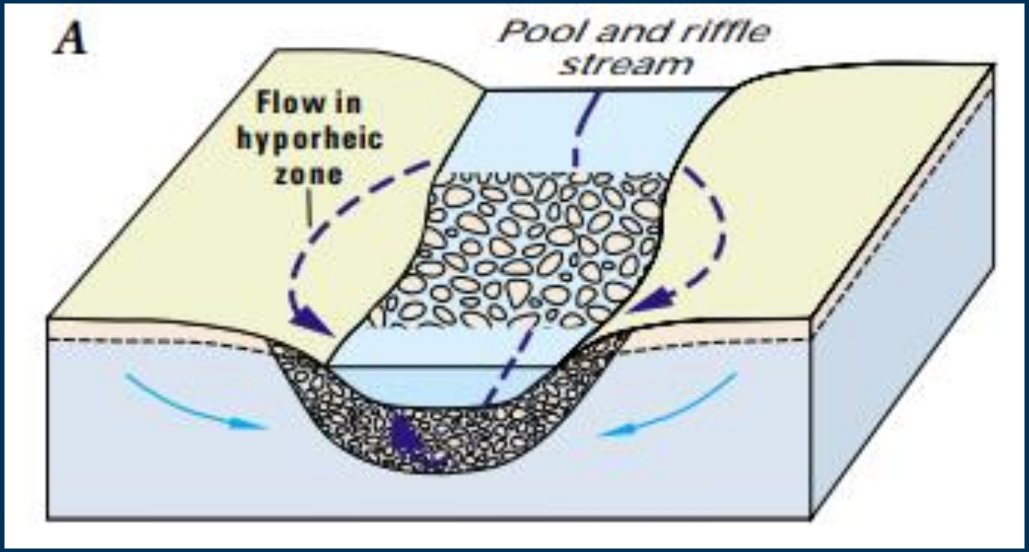
Physical Factors – GW/SW exchange



What features promote exchange?

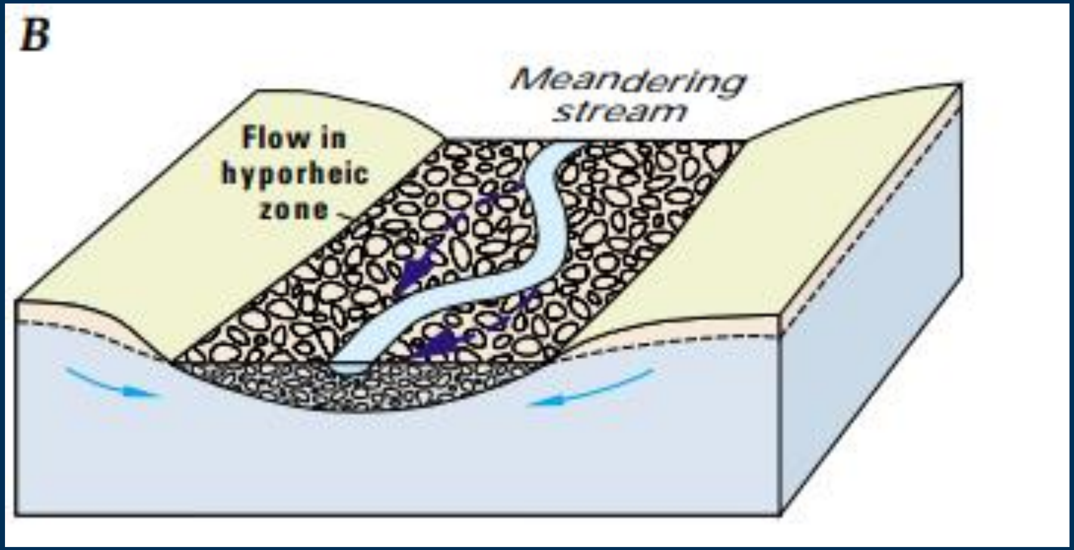
Physical Factors – GW/SW exchange



Channel slope

Pool-riffle sequences

Sinuosity



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Physical Factors – GW/SW exchange

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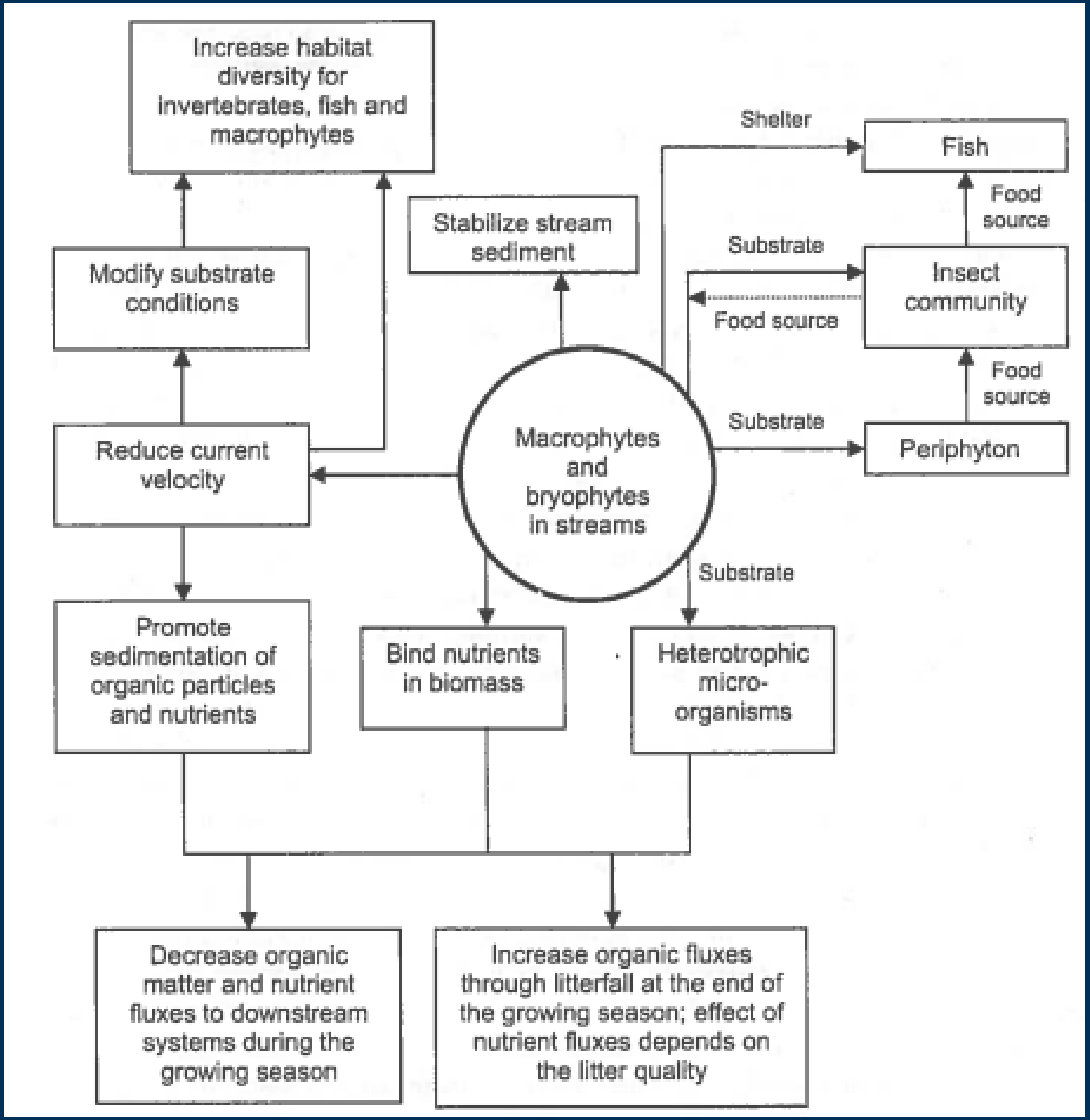
Biological Factors – plants

Biological Factors – plants

- Plants and algae can slow down flow
- They can take up nutrients for growth
- AND……

Biological Factors – plants



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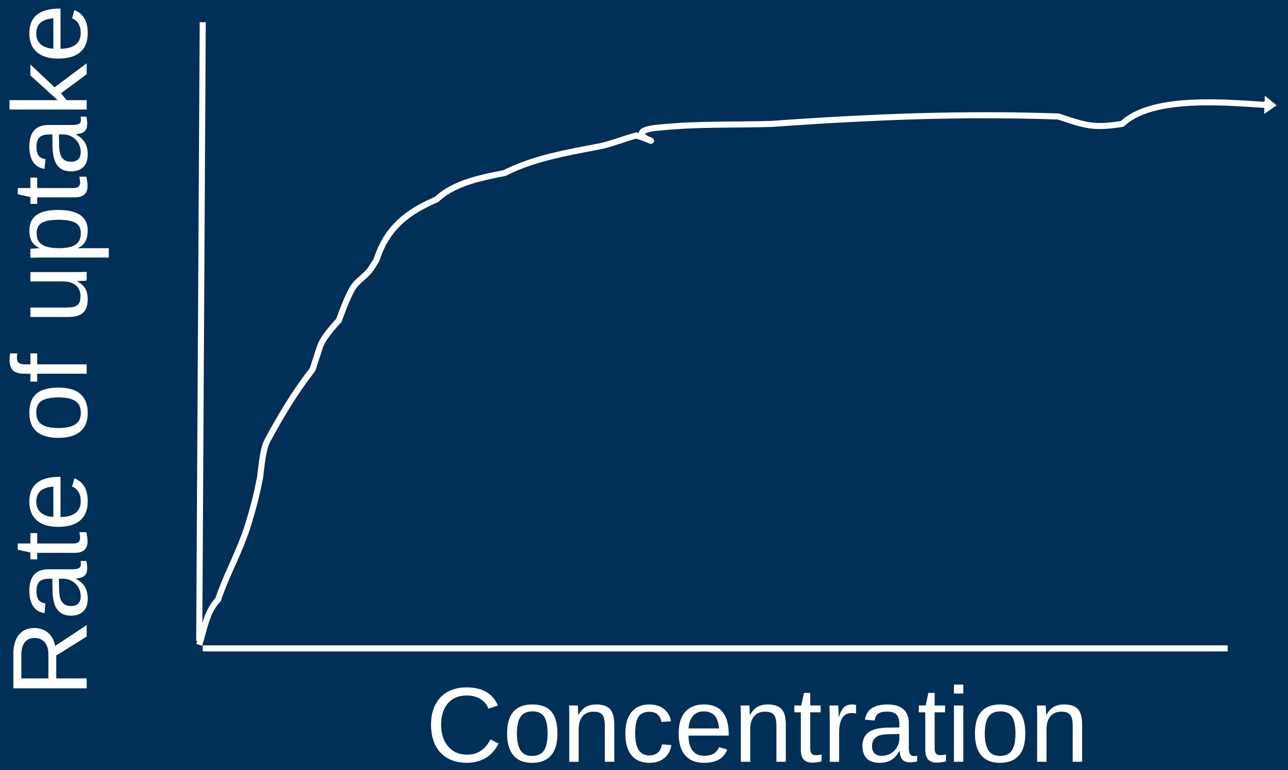
Chemical Factors

- You need nutrients in order to process them
  - Saturation kinetics



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Chemical Factors

- Dissolved Oxygen
  - Denitrification is an anoxic process and net loss of nitrogen

- Dissolved organic Carbon

- Fine benthic organic matter

- Temperature – a key factor for biological reactions

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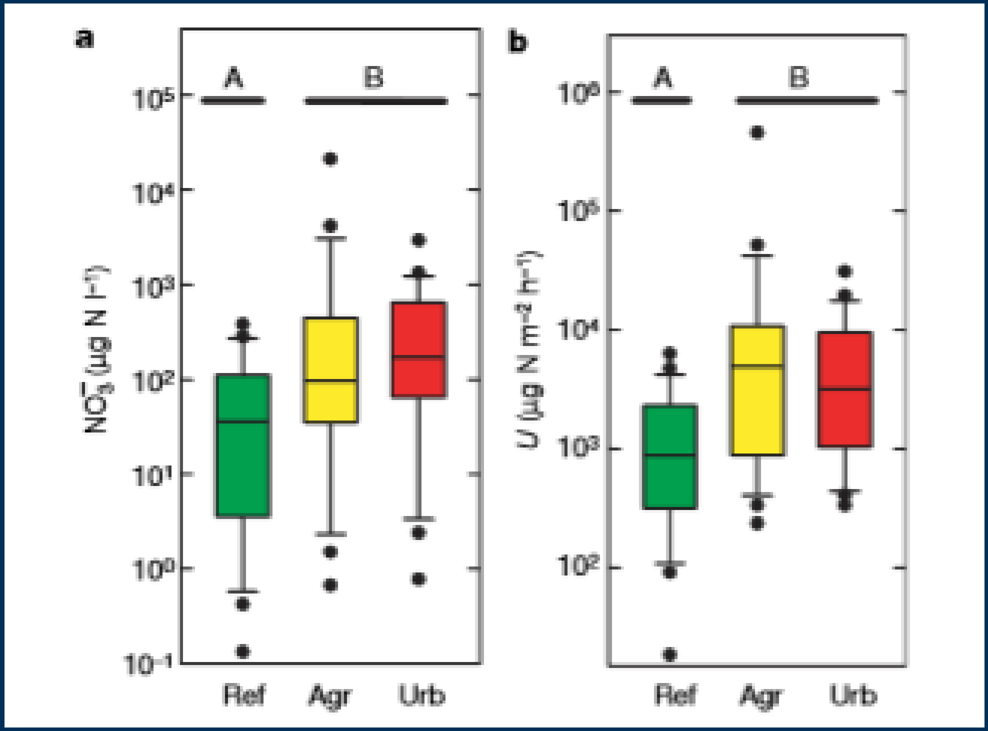
Don't forget……watershed factors!

- Population
- Impervious surface, urban development
- Drainage basin size



Estimating attenuation in Puget Sound

$$R = 1 - \exp(v_f/H_L)$$

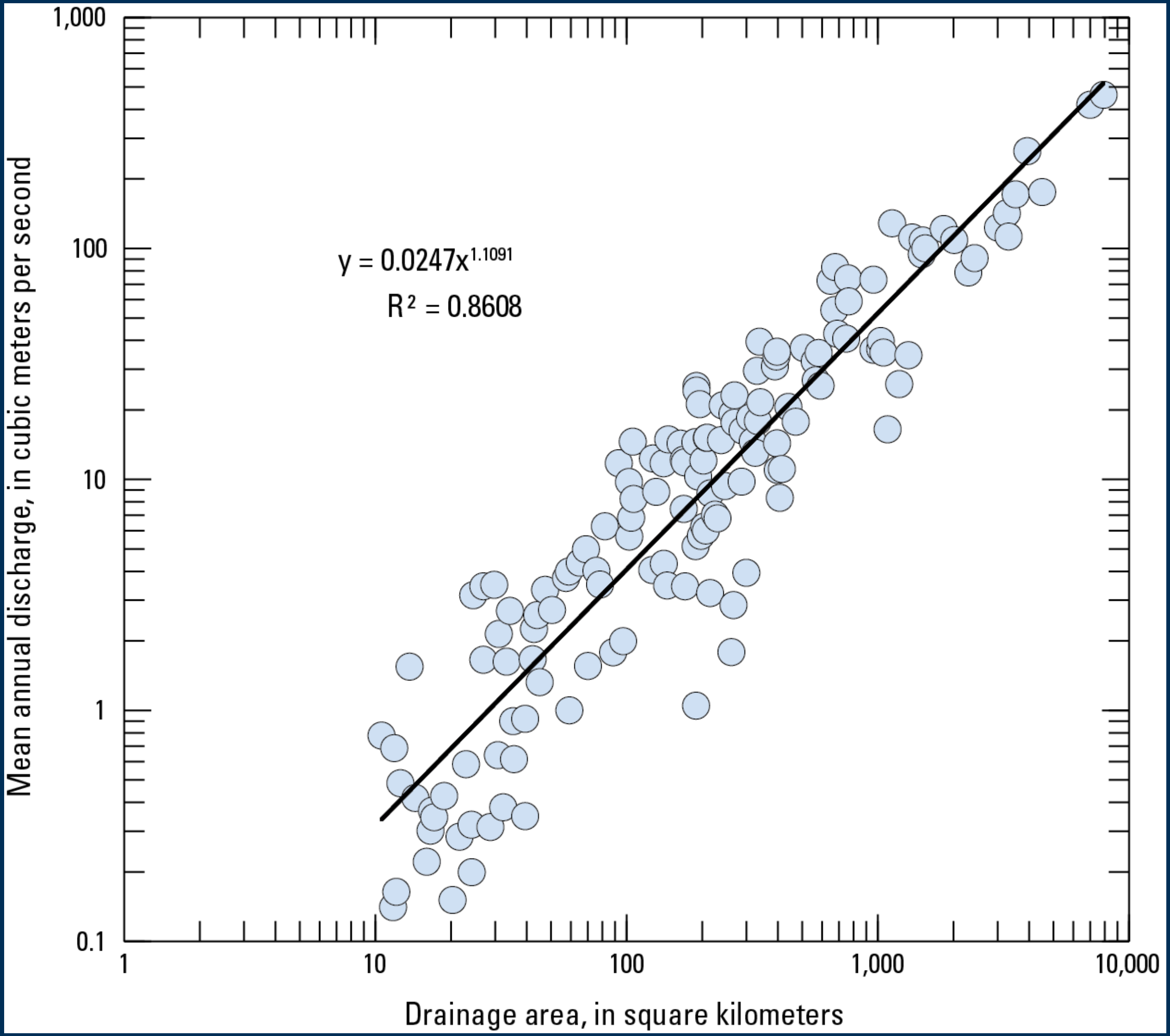
R = removal as fraction of inputs

V_f = uptake velocity

H_L = Q/wL

Can we estimate these for Puget Sound?

Estimating attenuation in Puget Sound



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$w = 4.85 * Qm^{0.48} / 3.281$

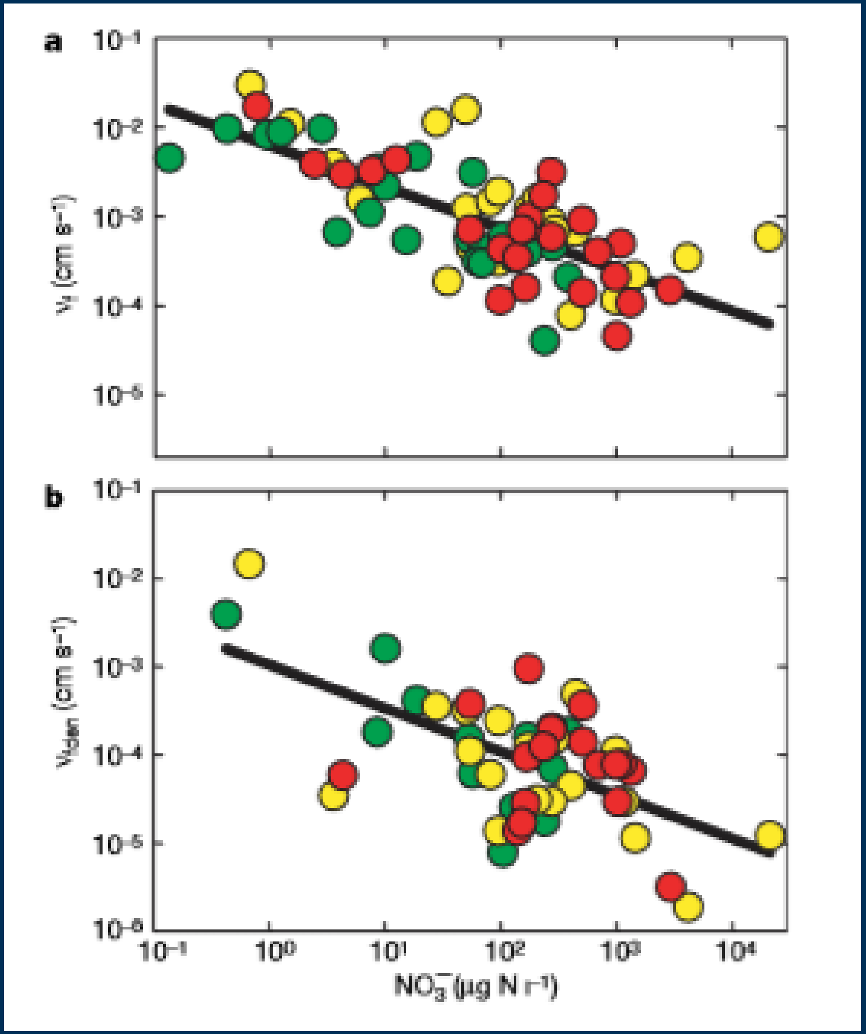
Estimating attenuation in Puget Sound

$$v_f = aC^b$$

Takes into account saturation at high concentration

$$v_f = 0.41[NO3]^{-0.39}$$

Aguileria et. al, 2013



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Estimating attenuation in Puget Sound

- Applied model to 17 major river drainages in Puget Sound
- Leveraged ongoing work at the time
  - Sub-watersheds were delineated
  - Detailed GIS information available
    - Channel widths, slopes, sinuosity

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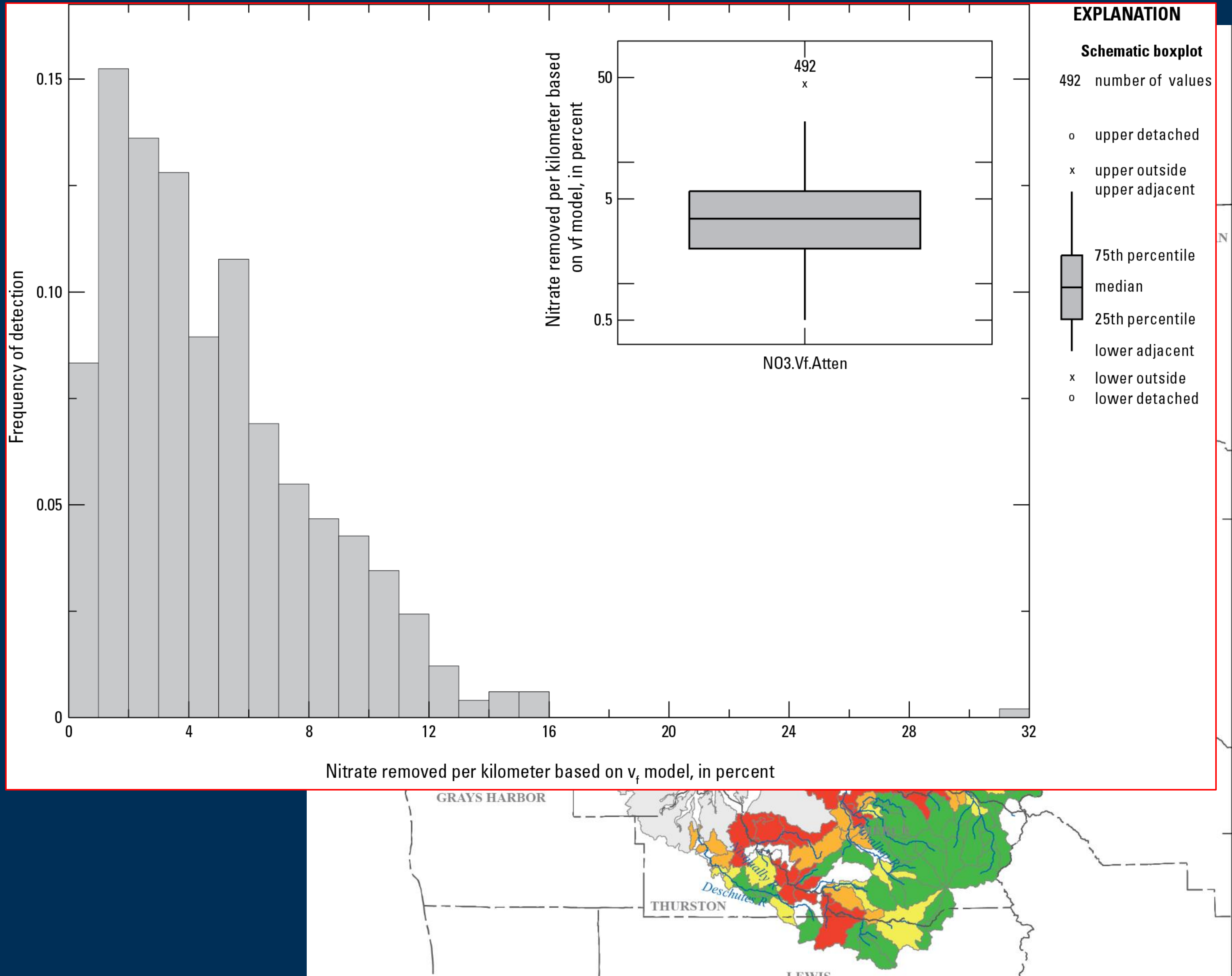
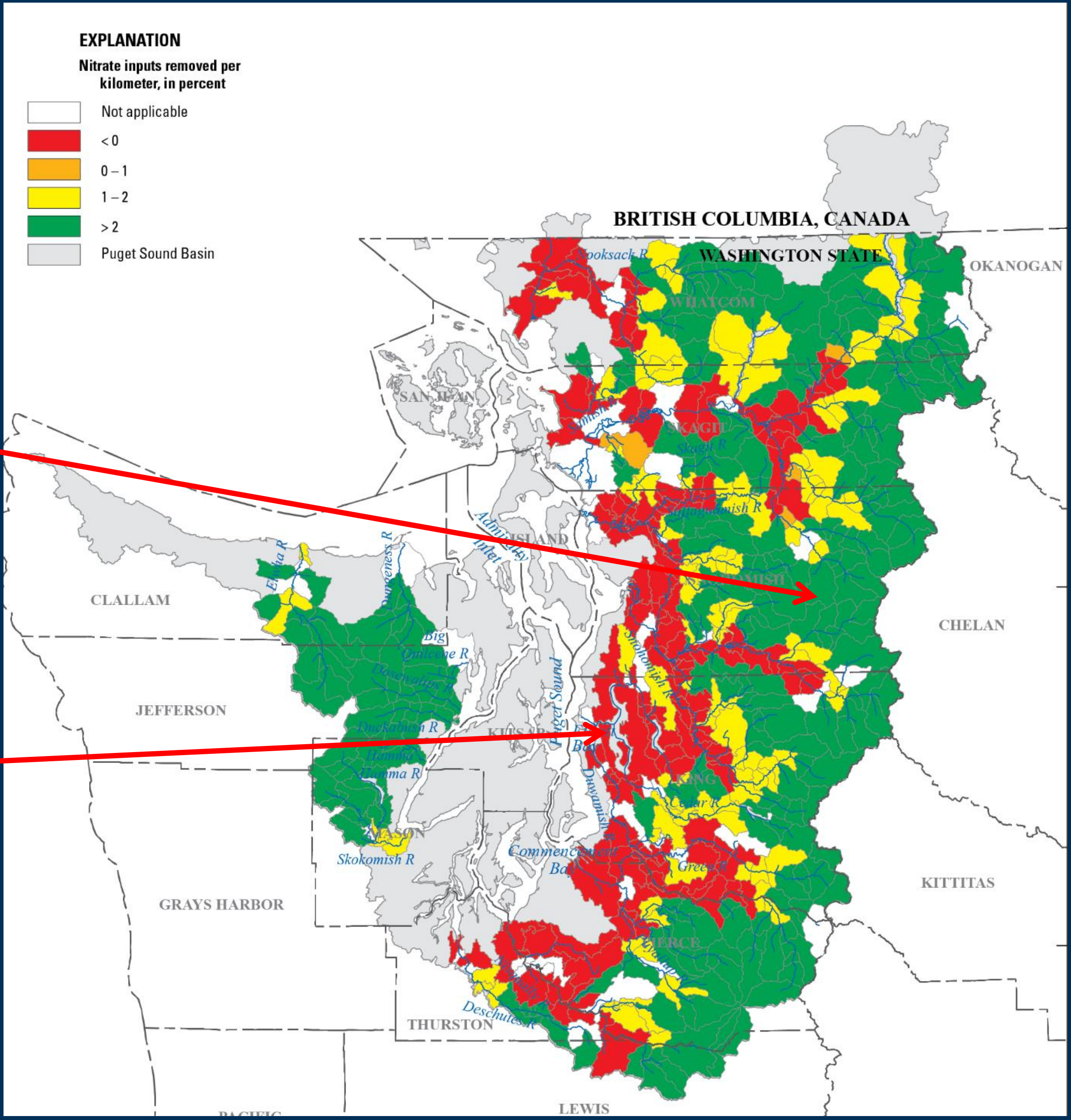
Model estimates



Hydrologic versus biologic controls

Upper watersheds biologic controls more important

Lower watersheds hydrologic controls more important



Developing a score card for attenuation

- We chose 4 primary factors related to attenuation
  - vf – chemical/biological influence
  - Q/w - specific discharge, indicates how much surface water in contact with streambed
  - Slope – surface water slope for estimating exchange
  - Sinuosity – another estimate of exchange potential

Developing a score card for attenuation

- For each factor, determined break points to assign a score of 0 or 1
  - Breakpoints based on local data, data from the literature or professional judgement
- Data for reach slope and sinuosity from Puget Sound Watershed Characterization project
  - Sample size was a little lower, but using real data as much as possible

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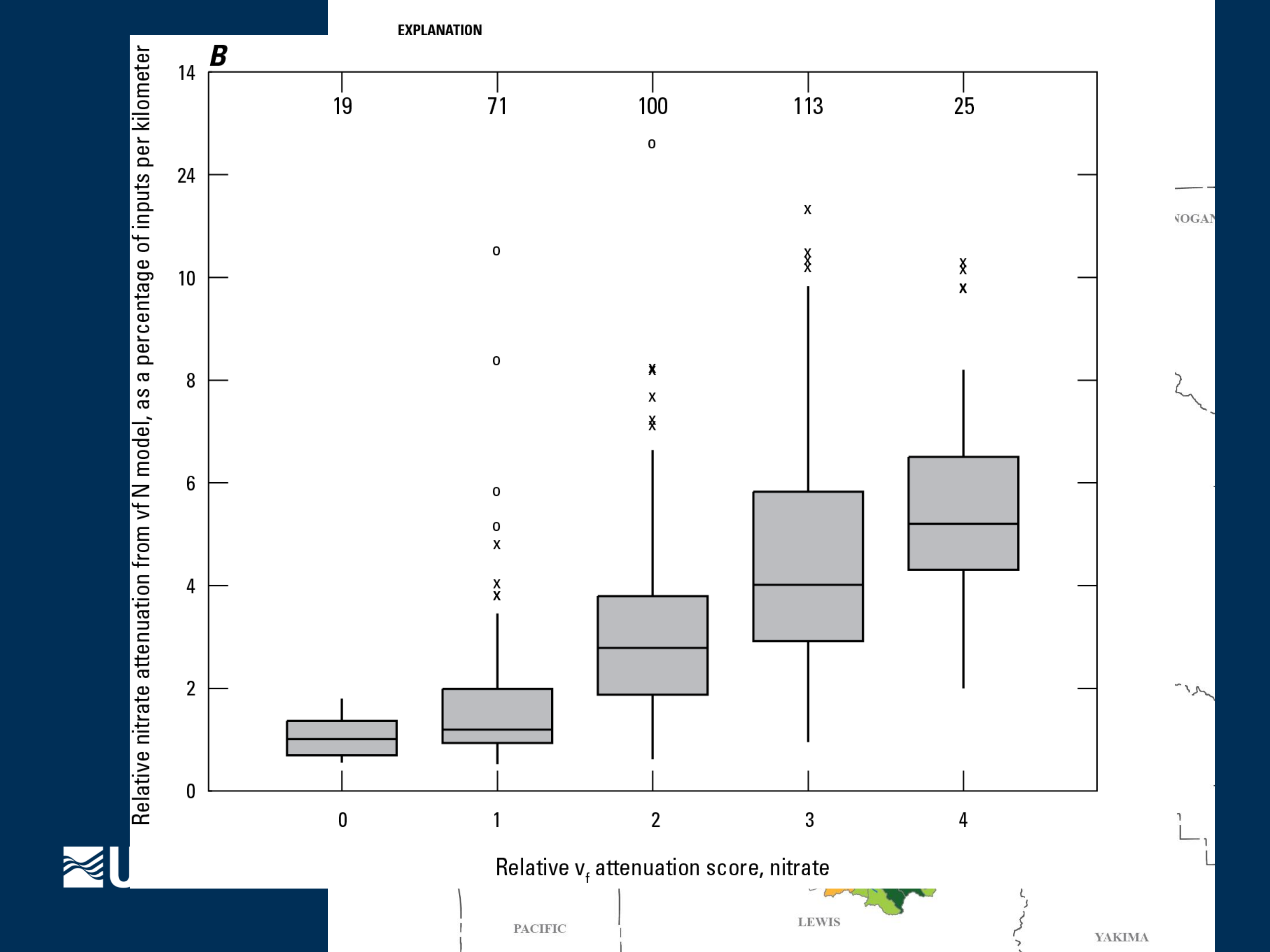

EXPLANATION
B
19
71
100
113
25
14
24
10
8
6
4
2
0
Relative nitrate attenuation from vf N model, as a percentage of inputs per kilometer
0
1
2
3
4
Relative v_f attenuation score, nitrate
PACIFIC
LEWIS
YAKIMA

What can we do moving forward?

- First, preserve those areas that show high attenuation potential
  - Small headwater streams
- Maintain important channel features
  - Large woody debris
  - Riparian vegetation
  - Channel complexity

What can we do moving forward?

- Restore function to channels where attenuation is low
  - Small headwater streams with high nutrient loads
  - Larger mainstem reaches
- Restoration activities can include
  - Large woody debris installation
  - Riparian vegetation replanting
  - Increasing substrate heterogeneity
  - Step-pool construction
  - Floodplain connectivity

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What can we do moving forward?

- Restore function to channels where attenuation is low
  - Small headwater streams with high nutrient loads
  - Larger mainstem reaches
- Reduce point and non-point nutrient sources
  - Low impact development
  - Healthy and intact riparian zones

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Sound familiar?

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Questions?

Sheibley, R.W., Konrad, C.P., and Black, R.W., 2015, Nutrient attenuation in rivers and streams, Puget Sound Basin, Washington (ver. 1.1, February 2016): U.S. Geological Survey Scientific Investigations Report 2015–5074, 67 p.

http://dx.doi.org/10.3133/sir20155074

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