Nutrient Attenuation in streams and rivers in the Puget Sound watershed

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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

Mohamedali et al, 2011
Nutrient Loading from rivers and WWTPs

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.
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
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.
The nitrogen cycle

- **N inputs**
  - Import from upstream

- **Atmospheric N₂**

- **DON NH₄⁺ + NO₃⁻**
  - Stream water

- **Export to downstream**

**Cyanobacteria**

- **N₂**
  - N fixation

- **NH₄⁺**
  - Assimilation

- **NO₃⁻**
  - Assimilation

**Benthic algae and microbes**

- **NO₂⁻**
  - Assimilation

**Dead organic matter and microbes**

- **NH₄⁺**
  - Excretion

- **NO₃⁻**
  - Nitrification

**Groundwater dissolved organic nitrogen, nitrate, ammonium**

**Denitrification**

- **NO₂⁻**
  - Mineralization
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
Physical Factors – stream order

- Lower order streams tend to be better at processing than higher order streams

- Many more 1st order streams in river networks than larger order streams

- More water contact with streambed

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)
Physical Factors – channel complexity
Physical Factors – Surface storage

Side pools, back waters, eddies
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
Physical Factors – GW/SW exchange
Physical Factors – GW/SW exchange

What features promote exchange?
Physical Factors – GW/SW exchange

Channel slope
Pool-riffle sequences
Sinuosity
Physical Factors – GW/SW exchange
Biological Factors – plants
Biological Factors – plants

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

- Increase habitat diversity for invertebrates, fish and macrophytes
- Modify substrate conditions
- Reduce current velocity
- Promote sedimentation of organic particles and nutrients
- Stabilize stream sediment
- Bind nutrients in biomass
- Heterotrophic micro-organisms

- Decrease organic matter and nutrient fluxes to downstream systems during the growing season
- Increase organic fluxes through litterfall at the end of the growing season; effect of nutrient fluxes depends on the litter quality

- Insect community
- Fish
- Periphyton
- Shelter
- Food source
Chemical Factors

- You need nutrients in order to process them
  - Saturation kinetics
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
Don’t forget......watershed factors!

- Population
- Impervious surface, urban development
- Drainage basin size
Estimating attenuation in Puget Sound

\[ R = 1 - \exp\left(\frac{v_f}{H_L}\right) \]

- \( R \) = removal as fraction of inputs
- \( V_f \) = uptake velocity
- \( H_L = \frac{Q}{wL} \)

Can we estimate these for Puget Sound?
Estimating attenuation in Puget Sound

\[ w = 4.85 \times Q_m^{0.48} / 3.281 \]

\[ y = 0.0247x^{1.1081} \]

\[ R^2 = 0.8608 \]
Estimating attenuation in Puget Sound

\[ v_f = aC^b \]

Takes into account saturation at high concentration

\[ v_f = 0.41[\text{NO}_3]^{-0.39} \]

Aguileria et al., 2013
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
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
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
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
Sound familiar?
Questions?


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