

# Exercise 5

Modelling Aquatic Ecosystems FS26

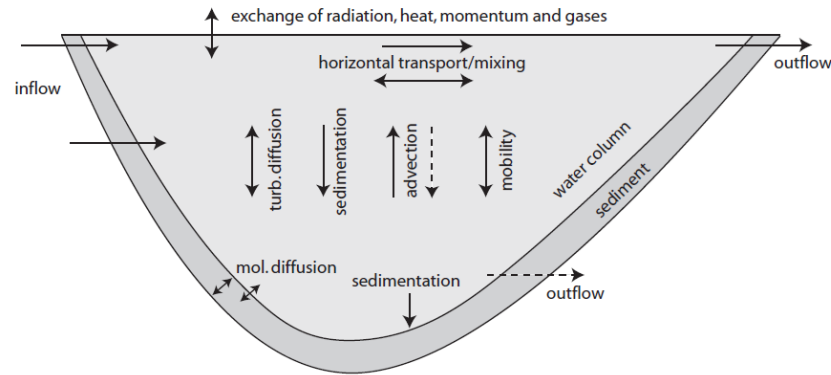
# Today's agenda

- Look at today's model (section 11.6)
- Work on the exercise on your own
- Break
- Discuss the questions of the exercise
- Work on your own model and take the opportunity to ask questions

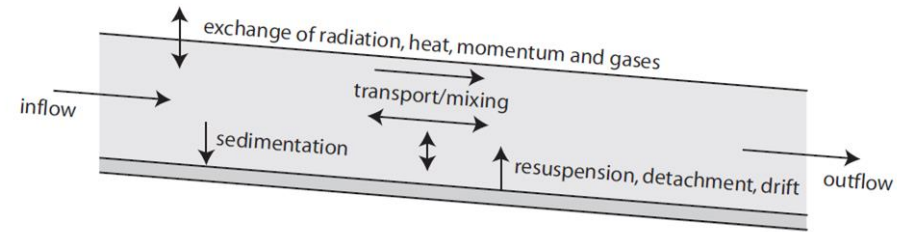
# Objectives of today's exercise

1. Learn the concepts and process formulations of the benthic river ecosystem with nutrient and dissolved oxygen dynamics in benthic river ecosystems
2. Build and simulate a river ecosystem model using the 'ecosim' package and understand the behavior.
3. Implement nitrification as 2-step processes in the model

# What are the dominant organisms in deep and shallow systems?



Suspended organisms  
(**phytoplankton**) dominate  
the overall nutrient cycle

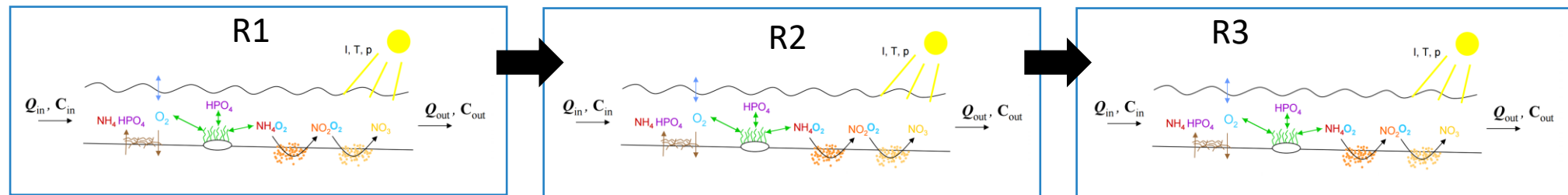


**Benthic** organisms  
dominate the overall  
nutrient cycle

It's easy to visualize that **most rivers are shallow** and **most lakes are deep**.  
However, we can find systems that will require us to model organisms differently  
(i.e. shallow lakes may experience more impact of benthic organisms).

# How to model a river?

## Physical Representation



### Biogeochem/ecological processes:

- 1 Growth, death, respiration:  
**benthic algae, heterotrophic bacteria**
- 2 Nitrification in two steps  $\rightarrow$  growth, death, respiration:  
**nitrosomonas (N1), nitrobacter (N2)**
- 3 Hydrolysis of **POM** (particulate) turning into  
**DOM** (dissolved)

### Environmental factors:

- 1 Temperature
- 2 Light intensity

# Process Table & Rate Expressions

Process		Substances / Organisms											Rate
		HPO <sub>4</sub> <sup>2-</sup> gP	NH <sub>4</sub> <sup>+</sup> gN	NO <sub>2</sub> <sup>-</sup> gN	NO <sub>3</sub> <sup>-</sup> gN	O <sub>2</sub> gO	DOM g	SALG gDM	SHET gDM	SN1 gDM	SN2 gDM	SPOM gDM	
benthic algae	Growth of algae NH <sub>4</sub> <sup>+</sup>	-	-			+		1					$\rho_{gro,SALG,NH_4^+}$
	Growth of algae NO <sub>3</sub> <sup>-</sup>	-			-	+		1					$\rho_{gro,SALG,NO_3^-}$
	Respiration of algae	+	+			-		-1					$\rho_{resp,SALG}$
	Death of algae	0/+	0/+			0/+		-1				Y <sub>ALG,death</sub>	$\rho_{death,SALG}$
heterotrophic bacteria	Growth of het. bact. NH <sub>4</sub> <sup>+</sup>	?	?			-	$\frac{-1}{Y_{HET}}$		1				$\rho_{gro,SHET,NH_4^+}$
	Growth of het. bact. NO <sub>3</sub> <sup>-</sup>	?			?	-	$\frac{-1}{Y_{HET}}$		1				$\rho_{gro,SHET,NO_3^-}$
	Respiration of het. bact.	+	+			-			-1				$\rho_{resp,SHET}$
	Death of het. bact.	0/+	0/+			0/+			-1			Y <sub>HET,death</sub>	$\rho_{death,SHET}$
nitrosomonas (N1)	Growth of N1	-	$\frac{-1}{Y_{N1}}$	+		-				1			$\rho_{gro,SN1}$
	Respiration of N1	+	+			-			-1				$\rho_{resp,SN1}$
	Death of N1	0/+	0/+			0/+			-1			Y <sub>N1,death</sub>	$\rho_{death,SN1}$
nitrobacter (N2)	Growth of N2	-		$\frac{-1}{Y_{N2}}$	+	-					1		$\rho_{gro,SN2}$
	Respiration of N2	+	+			-			-1				$\rho_{resp,SN2}$
	Death of N2	0/+	0/+			0/+			-1			Y <sub>N2,death</sub>	$\rho_{death,SN2}$
	Hydrolysis	0/+	0/+			0/+	Y <sub>hyd</sub>					-1	$\rho_{hyd}$

# Process Table & Rate Expressions

Rate	Rate expression
$\rho_{\text{gro,SALG,NH}_4^+}$	$k_{\text{gro,ALG},T_0} \cdot \exp(\beta_{\text{ALG}}(T - T_0)) \cdot \frac{I_0 \exp(-\lambda h)}{K_I + I_0 \exp(-\lambda h)} \cdot \min \left( \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{ALG}} + C_{\text{HPO}_4^{2-}}}, \frac{C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}{K_{\text{N,ALG}} + C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \right) \cdot \frac{p_{\text{NH}_4^+,\text{ALG}} C_{\text{NH}_4^+}}{p_{\text{NH}_4^+,\text{ALG}} C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \frac{K_{\text{sha,SALG}}}{K_{\text{sha,SALG}} + D_{\text{SALG}}} \cdot D_{\text{SALG}}$
$\rho_{\text{gro,SALG,NO}_3^-}$	$k_{\text{gro,ALG},T_0} \cdot \exp(\beta_{\text{ALG}}(T - T_0)) \cdot \frac{I_0 \exp(-\lambda h)}{K_I + I_0 \exp(-\lambda h)} \cdot \min \left( \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{ALG}} + C_{\text{HPO}_4^{2-}}}, \frac{C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}{K_{\text{N,ALG}} + C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \right) \cdot \frac{C_{\text{NO}_3^-}}{p_{\text{NH}_4^+,\text{ALG}} C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \frac{K_{\text{sha,SALG}}}{K_{\text{sha,SALG}} + D_{\text{SALG}}} \cdot D_{\text{SALG}}$
$\rho_{\text{resp,SALG}}$	$k_{\text{resp,ALG},T_0} \cdot \exp(\beta_{\text{ALG}}(T - T_0)) \cdot \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{ALG}} + C_{\text{O}_2}} \cdot D_{\text{SALG}}$
$\rho_{\text{death,SALG}}$	$k_{\text{death,ALG}} \cdot D_{\text{SALG}}$
$\rho_{\text{gro,SHET,NH}_4^+}$	$k_{\text{gro,HET},T_0} \cdot \exp(\beta_{\text{HET}}(T - T_0)) \cdot \frac{p_{\text{NH}_4^+,\text{HET}} C_{\text{NH}_4^+}}{p_{\text{NH}_4^+,\text{HET}} C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \cdot \min \left( \frac{C_{\text{DOM}}}{K_{\text{DOM,HET}} + C_{\text{DOM}}}, \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{HET}} + C_{\text{O}_2}}, \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{HET}} + C_{\text{HPO}_4^{2-}}}, \frac{C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}{K_{\text{N,HET}} + C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \right) \frac{K_{\text{lim,SHET}}}{K_{\text{lim,SHET}} + D_{\text{SHET}}} \cdot D_{\text{SHET}}$
$\rho_{\text{gro,SHET,NO}_3^-}$	$k_{\text{gro,HET},T_0} \cdot \exp(\beta_{\text{HET}}(T - T_0)) \cdot \frac{C_{\text{NO}_3^-}}{p_{\text{NH}_4^+,\text{HET}} C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \cdot \min \left( \frac{C_{\text{DOM}}}{K_{\text{DOM,HET}} + C_{\text{DOM}}}, \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{HET}} + C_{\text{O}_2}}, \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{HET}} + C_{\text{HPO}_4^{2-}}}, \frac{C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}{K_{\text{N,HET}} + C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \right) \frac{K_{\text{lim,SHET}}}{K_{\text{lim,SHET}} + D_{\text{SHET}}} \cdot D_{\text{SHET}}$
$\rho_{\text{resp,SHET}}$	$k_{\text{resp,HET},T_0} \cdot \exp(\beta_{\text{HET}}(T - T_0)) \cdot \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{HET}} + C_{\text{O}_2}} \cdot D_{\text{SHET}}$
$\rho_{\text{death,SHET}}$	$k_{\text{death,HET}} \cdot D_{\text{SHET}}$
$\rho_{\text{gro,SN1}}$	$k_{\text{gro,N1},T_0} \cdot \exp(\beta_{\text{N1}}(T - T_0)) \cdot \min \left( \frac{C_{\text{NH}_4^+}}{K_{\text{NH}_4^+,\text{nitr}} + C_{\text{NH}_4^+}}, \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{nitr}} + C_{\text{O}_2}}, \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{nitr}} + C_{\text{HPO}_4^{2-}}} \right) \frac{K_{\text{lim,SN}}}{K_{\text{lim,SN}} + D_{\text{SN1}}} \cdot D_{\text{SN1}}$
$\rho_{\text{resp,SN1}}$	$k_{\text{resp,N1},T_0} \cdot \exp(\beta_{\text{N1}}(T - T_0)) \cdot \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{nitr}} + C_{\text{O}_2}} \cdot D_{\text{SN1}}$
$\rho_{\text{death,SN1}}$	$k_{\text{death,N1}} \cdot D_{\text{SN1}}$
$\rho_{\text{gro,SN2}}$	$k_{\text{gro,N2},T_0} \cdot \exp(\beta_{\text{N2}}(T - T_0)) \cdot \min \left( \frac{C_{\text{NO}_2^-}}{K_{\text{NO}_2^-, \text{nitr}} + C_{\text{NO}_2^-}}, \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{nitr}} + C_{\text{O}_2}}, \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-}, \text{nitr}} + C_{\text{HPO}_4^{2-}}} \right) \frac{K_{\text{lim,SN}}}{K_{\text{lim,SN}} + D_{\text{SN2}}} \cdot D_{\text{SN2}}$
$\rho_{\text{resp,SN2}}$	$k_{\text{resp,N2},T_0} \cdot \exp(\beta_{\text{N2}}(T - T_0)) \cdot \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{nitr}} + C_{\text{O}_2}} \cdot D_{\text{SN2}}$
$\rho_{\text{death,SN2}}$	$k_{\text{death,N2}} \cdot D_{\text{SN2}}$
$\rho_{\text{hyd,SPOM}}$	$k_{\text{hyd,SPOM},T_0} \cdot \exp(\beta_{\text{hyd}}(T - T_0)) \cdot D_{\text{SPOM}}$

# Differences in self-inhibition terms

Discuss with others about the mechanical differences from modelling self-inhibition for planktonic algae and benthic bacteria!

## Growth of ALG on NH4

```
# Growth of algae on ammonium:
gro.ALG.NH4 <-
new(Class = "process",
name = "gro.ALG.NH4",
rate = expression(k.gro.ALG
  *exp(beta.ALG*(T-T0))
  *I0*exp(-lambda*h)/(K.I+I0*exp(
  lambda*h))
  *min(C.HPO4/(K.HPO4.ALG+C.HPO4),
  (C.NH4+C.NO3)/(K.N.ALG+C.NH4+C.NO3))
  *(p.NH4.ALG*C.NH4/(p.NH4.ALG*C.NH4+C.NO3))
  *D.ALG*K.shadow.ALG/(K.shadow.ALG+D.ALG)),
stoich = as.list(nu["gro.ALG.NH4",]),
pervol = F)
```

Inhibition term due to self-shading

## Growth of HET on NH4

```
# Growth of heterotrophic bacteria with ammonium:
gro.HET.NH4 <-
new(Class = "process",
name = "gro.HET.NH4",
rate = expression(k.gro.HET
  *exp(beta.HET*(T-T0))
  *min(C.DOM/(K.DOM.HET+C.DOM),
  C.O2/(K.O2.HET+C.O2),
  C.HPO4/(K.HPO4.HET+C.HPO4),
  (C.NH4+C.NO3)/(K.N.HET+C.NH4+C.NO3))
  *(p.NH4.HET*C.NH4/(p.NH4.HET*C.NH4+C.NO3))
  *D.HET*K.limit.HET/(K.limit.HET+D.HET)),
stoich = as.list(nu["gro.HET.NH4",]),
pervol = F)
```

The inhibition represents the diffusion limitation of nutrients into the benthic biofilm.

The larger the density (D.HET) of the biofilm, the more the diffusion of nutrients and thus the growth get inhibited.

Time to work on Exercise 5

## 2. What is the difference between planktonic primary production (modelled in the previous lake models) and benthic primary production (modelled in this river model)?

Rate	Rate expression
$\rho_{\text{gro,SALG,NH}_4^+}$	$k_{\text{gro,ALG},T_0} \cdot \exp(\beta_{\text{ALG}}(T - T_0)) \cdot \frac{I_0 \exp(-\lambda h)}{K_I + I_0 \exp(-\lambda h)} \cdot \min \left( \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{ALG}} + C_{\text{HPO}_4^{2-}}}, \frac{C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}{K_{\text{N,ALG}} + C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \right) \cdot \frac{p_{\text{NH}_4^+,\text{ALG}} C_{\text{NH}_4^+}}{p_{\text{NH}_4^+,\text{ALG}} C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \cdot D_{\text{SALG}}$

River

Lake

?

$$\bar{f}_{\text{rad}}^{\text{Monod}}(I_0, \lambda, h) = \frac{1}{\lambda h} \log \left( \frac{K_I + I_0}{K_I + I_0 \exp(-\lambda h)} \right),$$

**River:** Benthic algae growing at the bottom. No need for integration over depth of river.

$$f_{\text{rad}}^{\text{Monod}}(I) = \frac{I}{K_I + I}, \quad \text{where } I = I_0 \exp(-\lambda h)$$

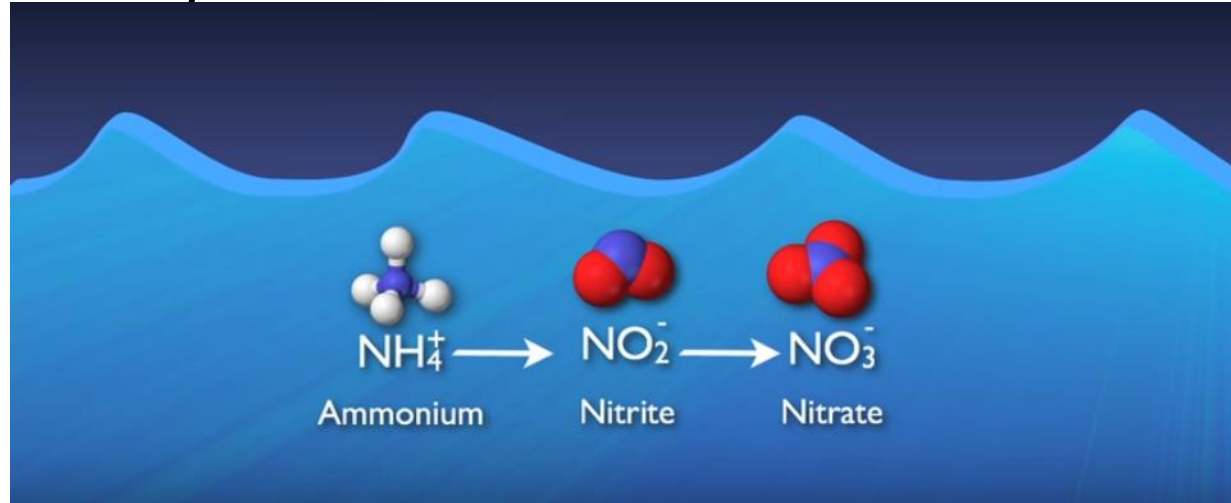
**Lake:** Phytoplankton growing in the water column. Light dependence of growth has to be integrated over depth.

$$\bar{f}_{\text{rad}}(I_0, \lambda, h) = \frac{1}{h} \int_0^h f_{\text{rad}}(I_0 \exp(-\lambda z)) dz$$

### 3. When should we model nitrification as a **one-step** or **two-step** process?

Rate	Rate expression
$\rho_{\text{gro,SALG,NH}_4^+}$	$k_{\text{gro,ALG},T_0} \cdot \exp(\beta_{\text{ALG}}(T - T_0)) \cdot \frac{I_0 \exp(-\lambda h)}{K_I + I_0 \exp(-\lambda h)} \cdot \min\left(\frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{ALG}} + C_{\text{HPO}_4^{2-}}}, \frac{C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}{K_{\text{N,ALG}} + C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}\right) \cdot \frac{p_{\text{NH}_4^+,\text{ALG}} C_{\text{NH}_4^+}}{p_{\text{NH}_4^+,\text{ALG}} C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \cdot D_{\text{SALG}}$
$\rho_{\text{gro,SALG,NO}_3^-}$	$k_{\text{gro,ALG},T_0} \cdot \exp(\beta_{\text{ALG}}(T - T_0)) \cdot \frac{I_0 \exp(-\lambda h)}{K_I + I_0 \exp(-\lambda h)} \cdot \min\left(\frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{ALG}} + C_{\text{HPO}_4^{2-}}}, \frac{C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}{K_{\text{N,ALG}} + C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}\right) \cdot \frac{C_{\text{NO}_3^-}}{p_{\text{NH}_4^+,\text{ALG}} C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \cdot D_{\text{SALG}}$
$\rho_{\text{resp,SALG}}$	$k_{\text{resp,ALG},T_0} \cdot \exp(\beta_{\text{ALG}}(T - T_0)) \cdot \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{ALG}} + C_{\text{O}_2}} \cdot D_{\text{SALG}}$
$\rho_{\text{death,SALG}}$	$k_{\text{death,ALG}} \cdot D_{\text{SALG}}$
$\rho_{\text{gro,SHET,NH}_4^+}$	$k_{\text{gro,HET},T_0} \cdot \exp(\beta_{\text{HET}}(T - T_0)) \cdot \frac{p_{\text{NH}_4^+,\text{HET}} C_{\text{NH}_4^+}}{p_{\text{NH}_4^+,\text{HET}} C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \cdot \min\left(\frac{C_{\text{DOM}}}{K_{\text{DOM,HET}} + C_{\text{DOM}}}, \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{HET}} + C_{\text{O}_2}}, \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{HET}} + C_{\text{HPO}_4^{2-}}}, \frac{C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}{K_{\text{N,HET}} + C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}\right) \cdot D_{\text{SHET}}$
$\rho_{\text{gro,SHET,NO}_3^-}$	$k_{\text{gro,HET},T_0} \cdot \exp(\beta_{\text{HET}}(T - T_0)) \cdot \frac{C_{\text{NO}_3^-}}{p_{\text{NH}_4^+,\text{HET}} C_{\text{NH}_4^+} + C_{\text{NO}_3^-}} \cdot \min\left(\frac{C_{\text{DOM}}}{K_{\text{DOM,HET}} + C_{\text{DOM}}}, \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{HET}} + C_{\text{O}_2}}, \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{HET}} + C_{\text{HPO}_4^{2-}}}, \frac{C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}{K_{\text{N,HET}} + C_{\text{NH}_4^+} + C_{\text{NO}_3^-}}\right) \cdot D_{\text{SHET}}$
$\rho_{\text{resp,SHET}}$	$k_{\text{resp,HET},T_0} \cdot \exp(\beta_{\text{HET}}(T - T_0)) \cdot \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{HET}} + C_{\text{O}_2}} \cdot D_{\text{SHET}}$
$\rho_{\text{death,SHET}}$	$k_{\text{death,HET}} \cdot D_{\text{SHET}}$
$\rho_{\text{gro,SN1}}$	$k_{\text{gro,N1},T_0} \cdot \exp(\beta_{\text{N1}}(T - T_0)) \cdot \min\left(\frac{C_{\text{NH}_4^+}}{K_{\text{NH}_4^+,\text{nitr1}} + C_{\text{NH}_4^+}}, \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{nitr1}} + C_{\text{O}_2}}, \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{nitr1}} + C_{\text{HPO}_4^{2-}}}\right) \cdot D_{\text{SN1}}$
$\rho_{\text{resp,SN1}}$	$k_{\text{resp,N1},T_0} \cdot \exp(\beta_{\text{N1}}(T - T_0)) \cdot \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{nitr1}} + C_{\text{O}_2}} \cdot D_{\text{SN1}}$
$\rho_{\text{death,SN1}}$	$k_{\text{death,N1}} \cdot D_{\text{SN1}}$
$\rho_{\text{gro,SN2}}$	$k_{\text{gro,N2},T_0} \cdot \exp(\beta_{\text{N2}}(T - T_0)) \cdot \min\left(\frac{C_{\text{NO}_2^-}}{K_{\text{NO}_2^-,\text{nitr2}} + C_{\text{NO}_2^-}}, \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{nitr2}} + C_{\text{O}_2}}, \frac{C_{\text{HPO}_4^{2-}}}{K_{\text{HPO}_4^{2-},\text{nitr2}} + C_{\text{HPO}_4^{2-}}}\right) \cdot D_{\text{SN2}}$
$\rho_{\text{resp,SN2}}$	$k_{\text{resp,N2},T_0} \cdot \exp(\beta_{\text{N2}}(T - T_0)) \cdot \frac{C_{\text{O}_2}}{K_{\text{O}_2,\text{nitr2}} + C_{\text{O}_2}} \cdot D_{\text{SN2}}$
$\rho_{\text{death,SN2}}$	$k_{\text{death,N2}} \cdot D_{\text{SN2}}$
$\rho_{\text{hyd,SPOM}}$	$k_{\text{hyd,SPOM},T_0} \cdot \exp(\beta_{\text{hyd}}(T - T_0)) \cdot D_{\text{SPOM}}$

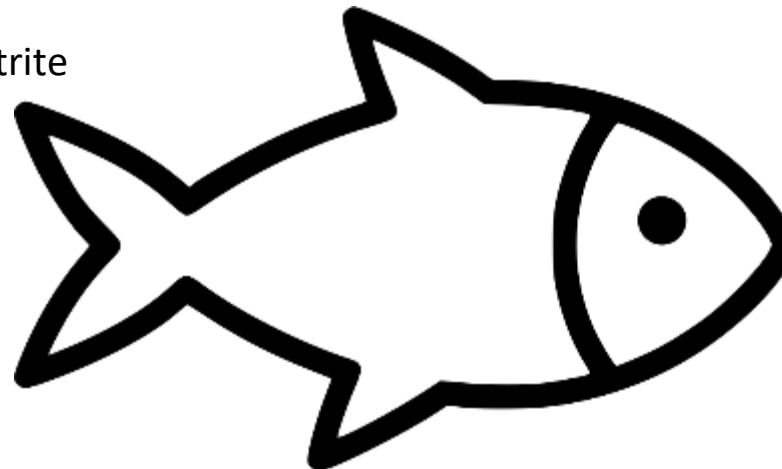
### 3. When should we model nitrification as a **one-step** or **two-step** process? (section 8.6)



Explanation video on nitrification and denitrification, related to waste water plant treatments:  
<https://www.youtube.com/watch?v=gF8rZVmuipw>

Based on your interest in the nitrite for **human** and **environmental** health protection

Nitrite is **toxic** to fish!



# Take home messages

1. Understand the ecosystem: Comprehend the key biogeochemical processes driving the benthic river ecosystem.
2. Connect the reactors: Simulate river flow dynamics by horizontally linking a series of reactors.
3. Define Your Scope: Choose between one- or two-step nitrification processes based on your specific research goals.

# Time to work on your own project

Deadlines: send us the code by **07.May** and your report by **22.May** !

Don't hesitate asking questions! (Also via email after class)

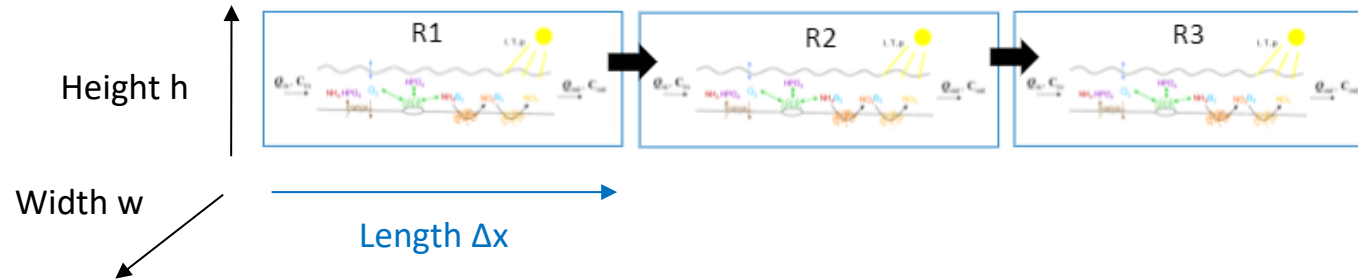
Submission:

Code submission: Chuxinyao Wang ([chuxinyao.wang@eawag.ch](mailto:chuxinyao.wang@eawag.ch)),

Visva Loganathan ([vloganathan@student.ethz.ch](mailto:vloganathan@student.ethz.ch))

Report submission: Nele Schuwirth ([nele.schuwirth@eawag.ch](mailto:nele.schuwirth@eawag.ch))

#### 4. What do you consider when deciding about the number and length of the boxes to discretize a river model?



Assumption: In our model the boxes are completely mixed reactors. Therefore, the **longitudinal dispersion coefficient** (eq. 6.65) is determined by **the length of the boxes**. If we choose a length that is too large, the mixing will be unrealistically large as well.

$$E_x = \frac{v\Delta x}{2} = \frac{Q\Delta x}{2wh} \quad (6.65)$$

Ideally, the length of the boxes should be chosen so that the **coefficient** matches the **estimated dispersion coefficient** described in eq. 6.61, or so that the **coefficient** is much smaller and we would then introduce a diffusion/dispersion process separately.

$$E_x \approx 0.011 \frac{w^2 v^2}{\sqrt{ghS_0}h} \quad (6.61)$$

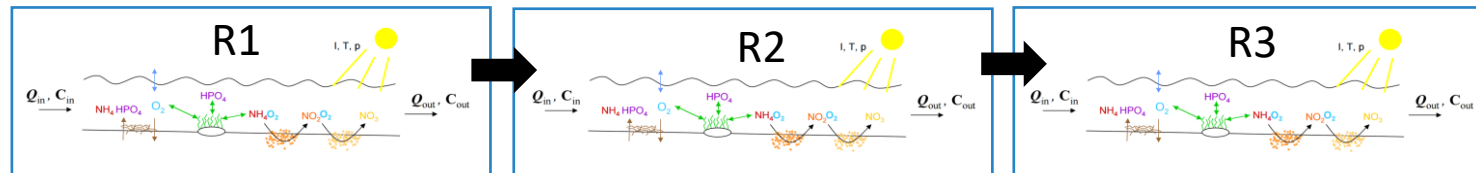
5. What is the importance of the advective transport process compared to the transformation processes for concentrations in the reactors ?

```
print(paste("hydraulic retention time: ",round(param$L*param$w*param$h/param$Q.in/86400,2),"d"))
print(paste("maximum inverse specific growth rate ALG: ",round(1/param$k.gro.ALG,2),"d"))
print(paste("maximum inverse specific growth rate HET: ",round(1/param$k.gro.HET,2),"d"))
print(paste("maximum inverse specific growth rate N1: ",round(1/param$k.gro.N1,2),"d"))
print(paste("maximum inverse specific growth rate N2: ",round(1/param$k.gro.N2,2),"d"))
print(paste("maximum inverse specific respiration rate ALG: ",round(1/param$k.resp.ALG,2),"d"))
print(paste("maximum inverse specific respiration rate HET: ",round(1/param$k.resp.HET,2),"d"))
print(paste("maximum inverse specific respiration rate N1: ",round(1/param$k.resp.N1,2),"d"))
print(paste("maximum inverse specific respiration rate N2: ",round(1/param$k.resp.N2,2),"d"))
print(paste("maximum inverse specific death rate ALG: ",round(1/param$k.death.ALG,2),"d"))
print(paste("maximum inverse specific death rate HET: ",round(1/param$k.death.HET,2),"d"))
print(paste("maximum inverse specific death rate N1: ",round(1/param$k.death.N1,2),"d"))
print(paste("maximum inverse specific death rate N2: ",round(1/param$k.death.N2,2),"d"))
print(paste("maximum inverse specific hydrolysis rate: ",round(1/param$k.hyd.POM,2),"d"))
```

## 5. What is the importance of the advective transport process compared to the transformation processes for concentrations in the reactors ?

```
## [1] "hydraulic retention time: 0.058 d"  
## [1] "maximum inverse specific growth rate ALG: 0.67 d"  
## [1] "maximum inverse specific growth rate HET: 0.67 d"  
## [1] "maximum inverse specific growth rate N1: 1.25 d"  
## [1] "maximum inverse specific growth rate N2: 0.91 d"  
## [1] "maximum inverse specific respiration rate ALG: 10 d"  
## [1] "maximum inverse specific respiration rate HET: 5 d"  
## [1] "maximum inverse specific respiration rate N1: 10 d"  
## [1] "maximum inverse specific respiration rate N2: 10 d"  
## [1] "maximum inverse specific death rate ALG: 10 d"  
## [1] "maximum inverse specific death rate HET: 5 d"  
## [1] "maximum inverse specific death rate N1: 10 d"  
## [1] "maximum inverse specific death rate N2: 10 d"  
## [1] "maximum inverse specific hydrolysis rate: 2 d"
```

The substances are being transferred **faster** than they are being transformed!



So, the biggest **contributor** to the movement of dissolved substances here is **advection**!