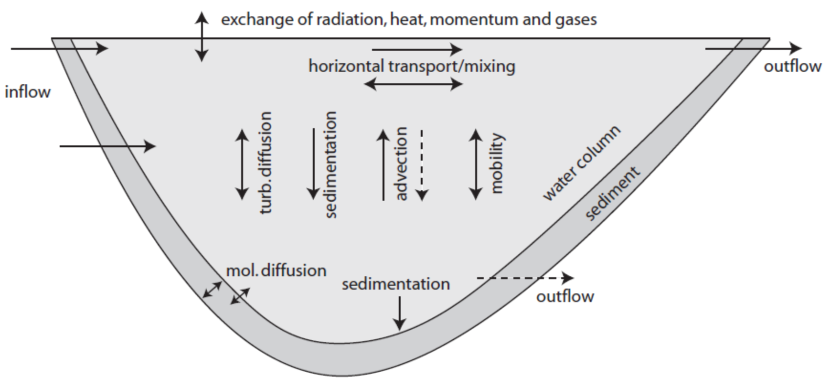
Exercise 5

Modelling Aquatic Ecosystems FS24

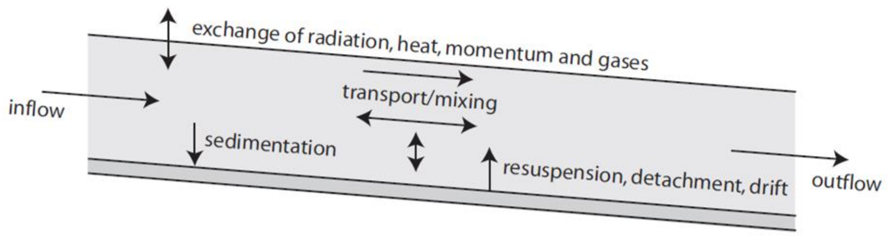
Today’s agenda

- 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

What are the dominant organisms in shallow and deep systems?



Suspended organisms (phytoplankton) dominate the overall nutrient cycle

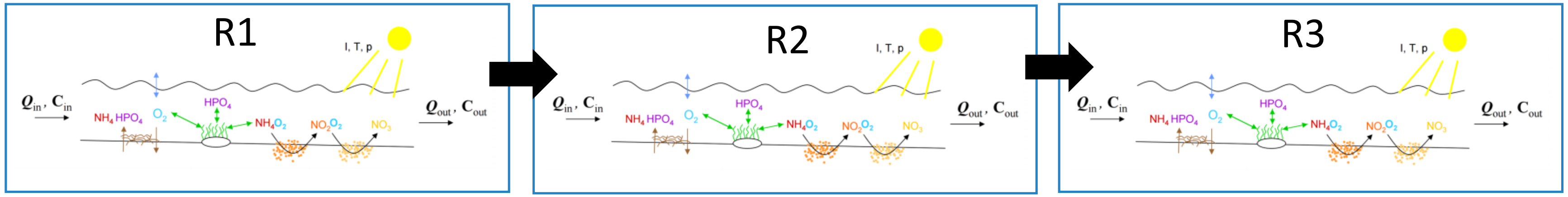


Benthic organisms dominate the overall nutrient cycle

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, **hetereotrophic bacteria**

2 Nitrification in two steps → growth, death, respiration:
nitrosomonas (N1), **nitrobacter** (N2)

3 Hydrolysis of **POM** (particulate) turning into
DOM (dissolved)

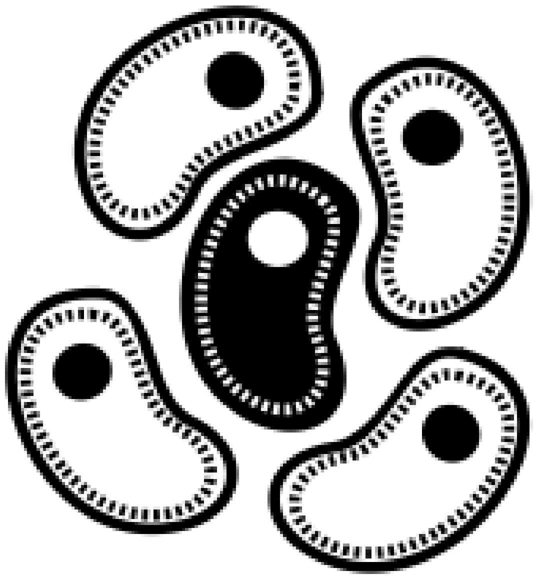
Environmental factors:

1 Temperature

2 Light intensity

Heterotrophic bacteria's yield

If Y.HET is equal to 0.6, how many grams of DOM should HET eat to gain 2 grams ?



In the manuscript:

POM	= Particulate OM
POMD	= Particulate OM Degradable
POMI	= Particulate OM Inert
SPOM	= Sedimented Particulate OM
DOM	= Dissolved OM

In the code:

C. = Substance concentration in the water column

D. = Substance density in the sediment

Differences in self-inhibition terms

Growth of ALG on NH4

```
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

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

River

Rate	Rate expression
$\rho_{\mathrm{gro,SALG,NH_4^+}}$	$k_{\mathrm{gro,ALG},T_0} \cdot \exp\Big(\beta_{\mathrm{ALG}}(T - T_0)\Big) \cdot \frac{I_0 \exp(-\lambda h)}{K_I + I_0 \exp(-\lambda h)} \cdot \min\left(\frac{C_{\mathrm{HPO_4^{2-}}}}{K_{\mathrm{HPO_4^{2-},ALG}} + C_{\mathrm{HPO_4^{2-}}}}, \frac{C_{\mathrm{NH_4^+}} + C_{\mathrm{NO_3^-}}}{K_{\mathrm{N,ALG}} + C_{\mathrm{NH_4^+}} + C_{\mathrm{NO_3^-}}}\right) \cdot \frac{p_{\mathrm{NH_4^+,ALG}} C_{\mathrm{NH_4^+}}}{p_{\mathrm{NH_4^+,ALG}} C_{\mathrm{NH_4^+}} + C_{\mathrm{NO_3^-}}} \cdot D_{\mathrm{SALG}}$

?

Lake

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

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

$$f_{\mathrm{rad}}^{\mathrm{Monod}}(I) = \frac{I}{K_I + I} ,$$

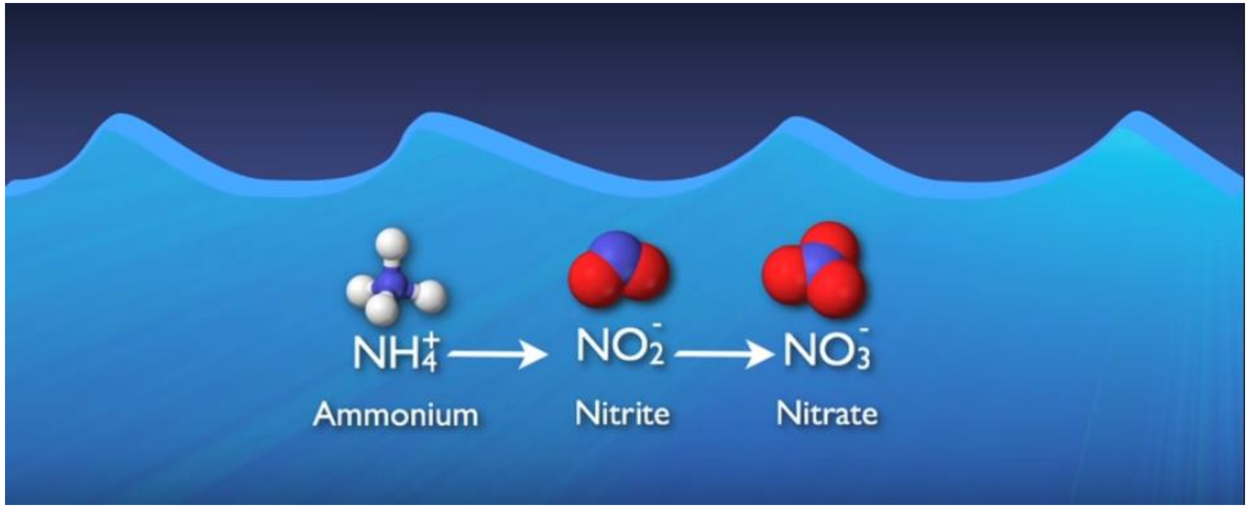
Lake: Phytoplankton growing in the water column. Light dependence of growth has to be integrated and averaged over depth.

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

When should we model nitrification as a one-step or two-step process?

Rate	Rate expression
$\rho_{gro,SALG,NH_4^+}$	$k_{gro,ALG,T_0} \cdot \exp\left(\beta_{ALG}(T-T_0)\right) \cdot \frac{I_0 \exp(-\lambda h)}{K_I + I_0 \exp(-\lambda h)} \cdot \min\left(\frac{C_{HPO_4^{2-}}}{K_{HPO_4^{2-},ALG} + C_{HPO_4^{2-}}}, \frac{C_{NH_4^+} + C_{NO_3^-}}{K_{N,ALG} + C_{NH_4^+} + C_{NO_3^-}}\right) \cdot \frac{p_{NH_4^+,ALG} C_{NH_4^+}}{p_{NH_4^+,ALG} C_{NH_4^+} + C_{NO_3^-}} \cdot D_{SALG}$
$\rho_{gro,SALG,NO_3^-}$	$k_{gro,ALG,T_0} \cdot \exp\left(\beta_{ALG}(T-T_0)\right) \cdot \frac{I_0 \exp(-\lambda h)}{K_I + I_0 \exp(-\lambda h)} \cdot \min\left(\frac{C_{HPO_4^{2-}}}{K_{HPO_4^{2-},ALG} + C_{HPO_4^{2-}}}, \frac{C_{NH_4^+} + C_{NO_3^-}}{K_{N,ALG} + C_{NH_4^+} + C_{NO_3^-}}\right) \cdot \frac{C_{NO_3^-}}{p_{NH_4^+,ALG} C_{NH_4^+} + C_{NO_3^-}} \cdot D_{SALG}$
$\rho_{resp,SALG}$	$k_{resp,ALG,T_0} \cdot \exp\left(\beta_{ALG}(T-T_0)\right) \cdot \frac{C_{O_2}}{K_{O_2,ALG} + C_{O_2}} \cdot D_{SALG}$
$\rho_{death,SALG}$	$k_{death,ALG} \cdot D_{SALG}$
$\rho_{gro,SHET,NH_4^+}$	$k_{gro,HET,T_0} \cdot \exp\left(\beta_{HET}(T-T_0)\right) \cdot \frac{p_{NH_4^+,HET} C_{NH_4^+}}{p_{NH_4^+,HET} C_{NH_4^+} + C_{NO_3^-}} \cdot \min\left(\frac{C_{DOM}}{K_{DOM,HET} + C_{DOM}}, \frac{C_{O_2}}{K_{O_2,HET} + C_{O_2}}, \frac{C_{HPO_4^{2-}}}{K_{HPO_4^{2-},HET} + C_{HPO_4^{2-}}}, \frac{C_{NH_4^+} + C_{NO_3^-}}{K_{N,HET} + C_{NH_4^+} + C_{NO_3^-}}\right) \cdot D_{SHET}$
$\rho_{gro,SHET,NO_3^-}$	$k_{gro,HET,T_0} \cdot \exp\left(\beta_{HET}(T-T_0)\right) \cdot \frac{C_{NO_3^-}}{p_{NH_4^+,HET} C_{NH_4^+} + C_{NO_3^-}} \cdot \min\left(\frac{C_{DOM}}{K_{DOM,HET} + C_{DOM}}, \frac{C_{O_2}}{K_{O_2,HET} + C_{O_2}}, \frac{C_{HPO_4^{2-}}}{K_{HPO_4^{2-},HET} + C_{HPO_4^{2-}}}, \frac{C_{NH_4^+} + C_{NO_3^-}}{K_{N,HET} + C_{NH_4^+} + C_{NO_3^-}}\right) \cdot D_{SHET}$
$\rho_{resp,SHET}$	$k_{resp,HET,T_0} \cdot \exp\left(\beta_{HET}(T-T_0)\right) \cdot \frac{C_{O_2}}{K_{O_2,HET} + C_{O_2}} \cdot D_{SHET}$
$\rho_{death,SHET}$	$k_{death,HET} \cdot D_{SHET}$
$\rho_{gro,SN1}$	$k_{gro,N1,T_0} \cdot \exp\left(\beta_{N1}(T-T_0)\right) \cdot \min\left(\frac{C_{NH_4^+}}{K_{NH_4^+,nitri} + C_{NH_4^+}}, \frac{C_{O_2}}{K_{O_2,nitri} + C_{O_2}}, \frac{C_{HPO_4^{2-}}}{K_{HPO_4^{2-},nitri} + C_{HPO_4^{2-}}}\right) \cdot D_{SN1}$
$\rho_{resp,SN1}$	$k_{resp,N1,T_0} \cdot \exp\left(\beta_{N1}(T-T_0)\right) \cdot \frac{C_{O_2}}{K_{O_2,nitri} + C_{O_2}} \cdot D_{SN1}$
$\rho_{death,SN1}$	$k_{death,N1} \cdot D_{SN1}$
$\rho_{gro,SN2}$	$k_{gro,N2,T_0} \cdot \exp\left(\beta_{N2}(T-T_0)\right) \cdot \min\left(\frac{C_{NO_3^-}}{K_{NO_3^-,nitri} + C_{NO_3^-}}, \frac{C_{O_2}}{K_{O_2,nitri} + C_{O_2}}, \frac{C_{HPO_4^{2-}}}{K_{HPO_4^{2-},nitri} + C_{HPO_4^{2-}}}\right) \cdot D_{SN2}$
$\rho_{resp,SN2}$	$k_{resp,N2,T_0} \cdot \exp\left(\beta_{N2}(T-T_0)\right) \cdot \frac{C_{O_2}}{K_{O_2,nitri} + C_{O_2}} \cdot D_{SN2}$
$\rho_{death,SN2}$	$k_{death,N2} \cdot D_{SN2}$
$\rho_{hyd,SPOM}$	$k_{hyd,SPOM,T_0} \cdot \exp\left(\beta_{hyd}(T-T_0)\right) \cdot D_{SPOM}$

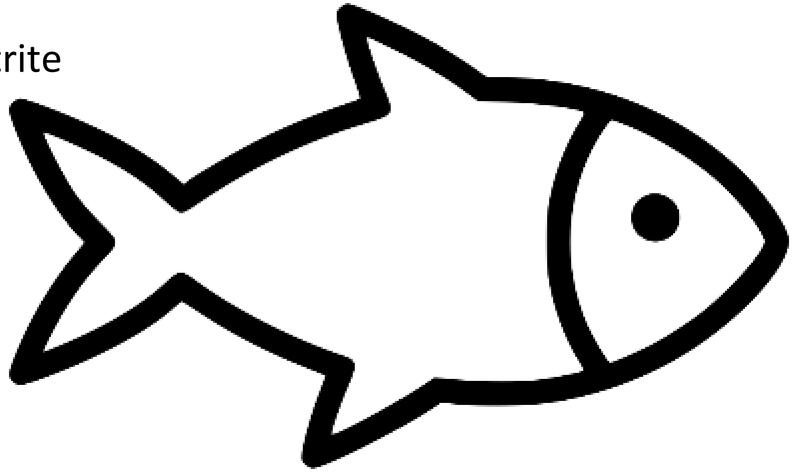
When should we model nitrification as a one-step or two-step process? (section 8.6)



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

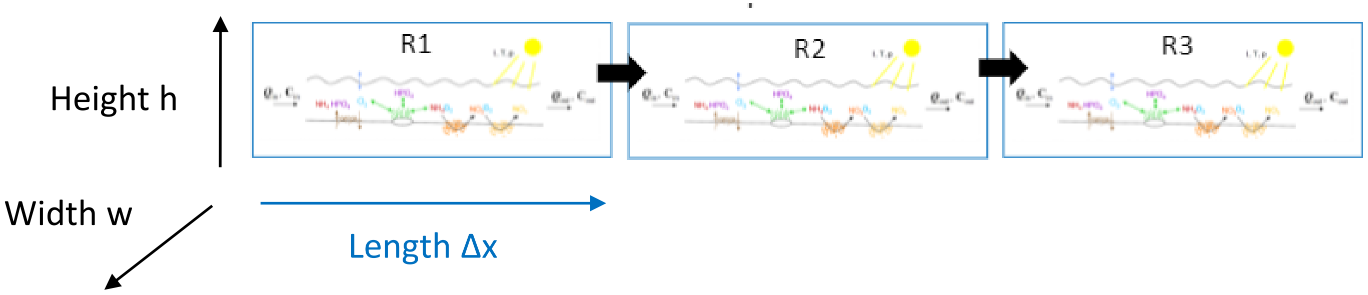
Nitrites are toxic to fish!



Time to work on your own project

Deadlines: send us the code by **tomorrow 09.05** and your report by **24.05** !

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.

$$E_x \approx 0.011 \frac{w^2 v^2}{\sqrt{g h S_0} h} \quad (6.61)$$

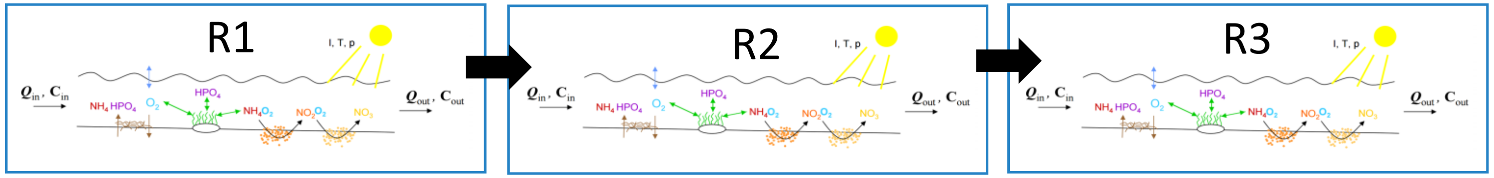
What is the importance of the advective transport process compared to the transformation processes for concentrations in the reactors ?

```
print(paste("hydraulic retention time:                    ",round(param$L*param$w*param$h/param$Q.in/8
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"))
```

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!