DHI 3 Algae and Sediment Model

MIKE ECO Lab Template

Scientific Description

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1 Introduction

MIKE ECO Lab is a numerical lab for Ecological Modelling. It is a generic and open tool for customising aquatic ecosystem models to describe for instance water quality and eutrophication. DHI's expertise and know how concerning ecological modelling has been collected in predefined ecosystem descriptions (MIKE ECO Lab templates) to be loaded and used in MIKE ECO Lab. So the MIKE ECO Lab templates describe physical, chemical and biological processes related to environmental problems and water pollution. The following is a description of the DHI 3 algae and sediment model.

The DHI 3 algae and sediment template is used in investigations of eutrophication effects where different algae species and sediment pools of nutrients are essential and as an instrument in environmental impact assessments for such ecosystems. The 3 algae and sediment modelling can be applied in environmental impact assessments considering:

- Pollution sources such as domestic and industrial sewage and agricultural run-off
- Cooling water outlets from power plants resulting in excess temperatures
- Physical conditions such as sediment loads and change in bed topography affecting especially the benthic vegetation
- Evaluation of action plans related to nutrient reductions
- Risk evaluation in connection to potential harmful algae blooms

The aim of using 3 algae and sediment modelling as an instrument in environmental impact assessment studies is to obtain, most efficiently in relation to economy and technology, the optimal solution with regards to ecology and the human environment.

The 3 algae and sediment model describes nutrient cycling including internal loadings from sediment pools of nutrient, phytoplankton and zooplankton growth, in addition to simulating oxygen conditions.

The model results describe the concentrations of phytoplankton, chlorophyll-a, zooplankton, organic matter (detritus), organic and inorganic nutrients, oxygen and the area-based sediment pools of nitrogen and phosphorous over time. In addition to this, a number of derived variables are stored: primary production, total nitrogen and phosphorus concentrations, sediment oxygen demand and Secchi disc depth.

The 3 algae and sediment template is integrated with the advection-dispersion module, which describes the physical transport processes at each grid-point covering the area of interest. Other data required are concentrations at model boundaries, flow and concentrations from pollution sources, water temperature and influx of light, etc.

2 Applications

The eutrophication template can be applied in a range of environmental investigations:

- Studies where the effects of alternative nutrient loading situations are compared and/or different waste water treatment strategies are evaluated.
- Studies of oxygen depletion.
- Studies of the effects of the discharge of cooling water.
- Comparisons of the environmental consequences of different construction concepts for harbours, bridges, etc.
- Evaluation of the environmental consequences of developing new urban and industrial areas.
- Evaluation of action plans related to nutrient reductions and long term effects of reduction scenarios.
- Risk evaluation in connection to potential harmful algae blooms.

3 Mathematical Formulations

The MIKE 21/3 ECO Lab is coupled to the MIKE 21/3 AD module in order to simulate the simultaneous processes of transport, dispersion and biological/biochemical processes.

The 3 algae and sediment model includes state variables for 3 pelagic algae groups, nutrients, oxygen, hydrogen sulphide and sediment pools of C, N and P as well as a number of sediment state variables..

Table 3.1 Pelagic state variables

Name	Comment	Unit
PC1	Flagellate C	g C m^{-3}
PC2	Diatom C	g C m^{-3}
PC3	Cyanobacteria C	g C m^{-3}
PN1	Flagellate N	g N m^{-3}
PN2	Diatom N	g N m^{-3}
PN3	Cyanobacteria N	g N m^{-3}
PP1	Flagellate P	g P m^{-3}
PP2	Diatom P	g P m^{-3}
PP 3	Cyanobacteria P	g P m^{-3}
Psi	Diatom Si	g Si m^{-3}
CH	Chlorophyll-a	g Chl m^{-3}
ZC	Zooplankton C	g C m^{-3}
DC	Detritus C	g C m^{-3}
DN	Detritus N	g N m^{-3}
DP	Detritus P	g P m^{-3}
DSi	Detritus Si	g Si m^{-3}
NH4	Total ammonia (NH_4)	g N m^{-3}
NO3	Nitrate+ nitrite	g N m^{-3}
H2S	Hydrogen Sulphide (H_2S)	g S m^{-3}
IP	Inorganic Phosphorous (PO_4)	g P m^{-3}
Si	Silicate Si	g Si m^{-3}
DO	Dissolved Oxygen	g O_2 m^{-3}
CDOC	Coloured refractory DOC	g C m^{-3}
CDON	Coloured refractory DON	g N m^{-3}
CDOP	Coloured refractory DOP	g P m^{-3}
LDOC	Labile DOC	g C m^{-3}
LDON	Labile DON	g N m^{-3}
LDOP	Labile DOP	g P m^{-3}

Table 3.2 Sediment state variables

Name	Comment	Unit
SSi	Sediment biological available Silicate	g Si m-2
KDOX	Oxidised layer, depth of NO3 penetration in sediment	m
KDO2	DO penetration into sediment	m
SOC	Sediment organic C	g C m-2
SON	Sediment organic N	g N m-2
SOP	Sediment organic P	g P m-2
FESP	Sediment iron adsorbed PO4	g P m-2
SNH	Sediment pore water NH4	g N m-2
SNO3	NO3-N in Surface sediment pore water, layer (0 - kdo2)	g N m-2
SIP	Sediment pore water PO4	g P m-2
SH2S	Sediment reduced substances as (H2S)	g S m-2
SPIM	Immobilised P in sediment	g P m-2
SNIM	Sediment immobilised N by denitrification & burial	g N m-2
SCIM	Sediment immobilised C by mineralisation & burial of SOC	g C m-2

Table 3.3 Additional State variables for mass considerations

Name	Comment	Unit
sum_PRPC	Sum of PC production	g C m-2
sum_CminW	Sum of pelagic C mineralisation	g C m-2
sum_minSOC	Sum of SOC mineralisation	g C m-2
sum_DEPON	Sum of atmospheric deposition of N	g N m-2
Sum_Nfix	Sum of cyanobaterial N fixation	g N m-2
sum_DENW	Sum of denitrification in water column	g N m-2
sum_Nflux	Sum of N flux sediment- water	g N m-2
sum_rdenit	Sum of sediment denitrification	g N m-2
sum_DEPOP	Sum of atmospheric deposition of P	g P m-2
sum_Pflux	Sum of P flux sediment-water	g P m-2
sum_rear	Sum of reaeration	g O2 m-2
sum_ODSC	Sum of sediment O2 respiration	g O2 m-2
sum_RSH2S	Sum of H2S production in sediment	g S m-2

The first 28 components or state variables (pelagic system) are moveable and treated in both the MIKE 21/3 AD and the MIKE 21/3 ECO Lab module. The additional components have a fixed nature belonging to the benthic system.

The processes and transfer of carbon, nitrogen and phosphorus in the Eutrophication model system is illustrated in Figure 3.1. Also included in the model is an oxygen balance.

The processes describing the variations of the components in time and space are dependent on external factors such as the salinity, water temperature, the light influx, and the discharges.

The salinity and water temperature can be results of MIKE 21/3 AD simulations or be user specified values. The first possibility is especially relevant for cooling water investigations whereas the latter possibility often is used in areas where only natural variations in temperature are seen.

The mathematical formulations of the biological and chemical processes and transformations for each state variable are described one by one below. The differential equations are 1st order, ordinary and coupled.

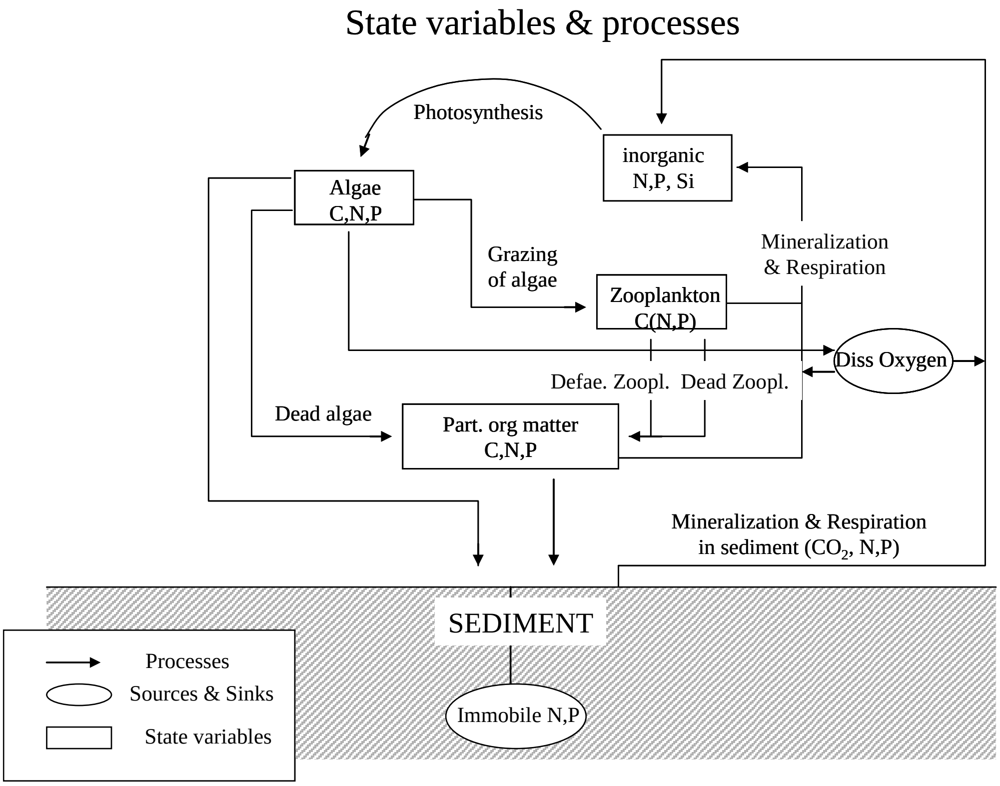

Figure 3.1 The simplified flow diagram of the fluxes of carbon, nitrogen and phosphorus in the eutrophication model.

3.1 Vertical light penetration

Light is essential for growth of all plants, including the pelagic. The vertical light penetration can be described by an exponential decay with depth which is dependent on a light extinction K_d, which either can be described as with light extinction constants (k_{dx}) multiplied by concentrations of light extinction concentration (Chlorophyll (CH, g m^{-3})), detritus (DC, g C m^{-3}), dissolved organic matter (CDOC, g C m^{-3}), inorganic matter (SS, g m^{-3}) and water(k_{bla}, m^{-1}) or it can be described as a function of scattering (b, m^{-1}) and absorption (a, m^{-1}) of light.

Vertical light penetration with depth (z, m) in the water column:

$$I_z = I_0 * e^{-K_{dx} * z} \text{ mol photons } m^2\ d^{-1} \tag{3.1}$$

Where K_{dx} can be either K_{d1} or K_{d2}:

$$K_{d1} = K_{chl} * CH + K_{dc} * DC + k_{cdoc} * CDOC + k_{ss} * SS + k_{bla}\ , m^{-1} \tag{3.2}$$

Or:

$$K_{d2} = \sqrt{a^2 + 0.256 * a * b\ , m^{-1}} \tag{3.3}$$

The absorption of light is mainly associated to particulate and dissolved organic matter whereas the scattering is mainly associated to particulate inorganic matter.

Light absorption, where the notation Kx_a stand for light absorption constant of component x:

$$a = K_{chl_a} * CH + K_{dc_a} * DC + K_{cdoc_a} * CDOC + K_{ss_a} * SS + k_{bla}\ \ , m^{-1} \tag{3.4}$$

Light scattering form phytoplankton and fine suspended inorganic matter can be describes as power functions of CH and SS:

$$b = bkch * CH^{ekch} + bkss * SS^{ekss}\ , m^{-1} \tag{3.5}$$

Where the light scattering constants (bkch, bkss in m^2g^{-1}) and exponents (ekch, ekss) are for chlorophyll and inorganic suspended matter, respectively.

The present ecological model do not simulate resuspensition of (fine) sediment, therefore SS is not dynamically simulated. Resuspension is most pronounced on shallow waters below 5-10 m. The user should therefore consider the need for either including measured SS concentrations or modelled concentrations of SS by a sediment transport model (MIKE by DHI 2011a). On shallow waters (like lagoons) the EU-MT MIKE ECO Lab template can be used. This template includes resuspension of and transport of fine sediment and combine it with a description of nutrients (N, P) one phytoplankton group, one macroalgae, one rooted macrophyte (eelgrass) and microbenthic algae (Rasmussen E. K. et al. 2009).

The present model however calculates dynamically the concentration of chlorophyll (CH), detritus carbon (DC) and refractory or coloured dissolved organic C (CDOC). The missing resuspension of SS is minimal if used on set up with waters above 10 m depth, like the Baltic Sea.

3.2 Production of autotrophs

The template includes 3 pelagic autotrophs (flagellates, diatoms and cyanobacteria). The production is based on daily dose of photosynthetic active light (PAR, mol photons $m^2 d^{-1}$) light resulting in a net production.

The differential equation includes a net production, sedimentation, buoyancy (flagellate & cyanobacteria) and mortality by grazing and nutrient limitation (nutrient stress).

$$\frac{dX}{dt} = gross\ production - mortality - sedimentation + \ boyancy \tag{3.6}$$

The net production is determined by light (*flight(i)*), temperature (*ftemp(T)*) and nutrient availability (*fnut(N,P, (Si diatoms))*). μ_T is the temperature corrected max specific growth (d^{-1}) and X is the biomass (g C m^{-3} or g C m^{-2})

$$net\ production = \mu_T * flight(i) * ftemp(T) * fnut\big(N, P, (Si)\big) * FAC * RD * X \tag{3.7}$$

Where:

Name	Comment	Unit
μ	Max specific net growth rate (12 h light/12 h dark) at 20 °C	d^{-1}
i	Light (PAR) dose	mol photon m^{-2} d^{-1}
T	Temperature	°C
N,P, Si	Internal concentrations of N, P and SI in algae	g nutrient g C^{-1}
FAC	Correction of dark reaction (growth)	n.u.
RD	Relative day length, function of latitude, 1 at 12 h light	n.u

Temperature is an important direct or indirect regulator of many processes. Two types of temperature functions are used, Arrhenius or Lassiter functions.

The Arrhenius function increases the process exponentially with temperature; whereas the Lassiter function have an optimum temperature from which the process decline towards zero.

In the present template Arrhenius relations are used to describe the max specific growth rates, as the template is used in waters where the temperature rarely exceeds 20 °C. Further at increasing temperatures the plankton community will have a tendency to adapt to the higher temperature by change of species composition.

The user is encouraged to consider the feasibility to change from Arrhenius to a Lassiter temperature regulation of the max specific growth rates if needed. Both Arrhenius and Lassiter expressions are bullied in function in MIKE ECO Lab see (MIKE by DHI 2011b).

Lassiter functions are used to temperature regulate the max specific growth rates. In contrast to the Arrhenius function The Lassiter function include an optimum temperature above which the function will decline. Arrhenius functions are used to regulate the specific growth of phytoplankton or macrophytes in areas normally having summer temperatures well above 20 °C.

It is still recommended to use Arrhenius functions for temperature regulation of respiration processes; however the user might consider to increase the reference temperature for 20 °C, if data or references justify this.

Lassiter:

$$L(T) = p_{opt} * e^{K2*(T-T_{opt})} * \left(\frac{(T_{max}-T)}{(T_{max}-T_{opt})}\right)^{K2*(T_{max}-T_{opt})}, d^{-1} \tag{3.8}$$

Arrhenius 20 °C:

$$A(T) = \theta^{(T-20)}, d^{-1} \tag{3.9}$$

Where:

T:	Temperature °C
ρopt:	max growth at Topt, d-1
Topt:	Optimum temperature °C
Tmaxt:	Maximum temperature° C
Ө:	Teta constant Arrhenius function
K2:	constant

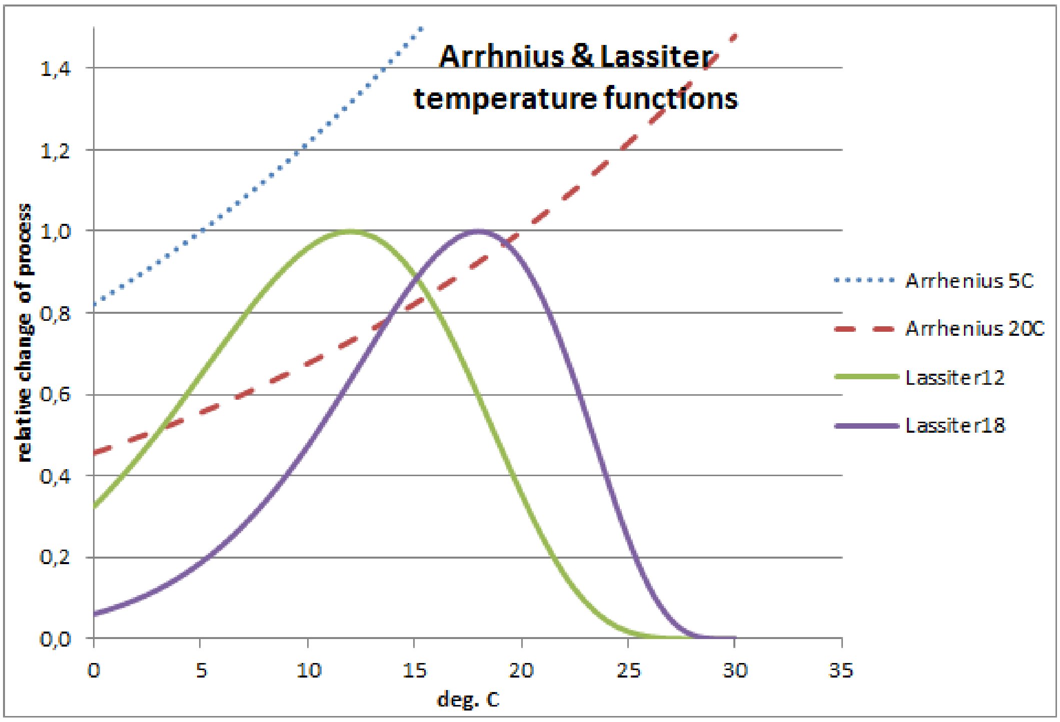

Figure 3.2 Arrhenius at 5 and 20 °C (Ө 1.04) and Lassiter function at T_{opt} at 12 and 18 °C (T_{max} 30 °C, K2 0.4)

The nutrient regulates the growth of all autotrophs. Two different nutrient regulators of the growth are used. A Droop kinetic (Droop 1973, Droop 1975) is used for autotrophs having internal nutrient pools (flagellates, diatoms, cyanobacteria). A Monod kinetics (Monod J. 1949) is used to describe the uptake of inorganic N, P and Si from the water into plankton.

Further cyanobacteria has the ability to N fixation in situation where the internal N:C ratio is low and the internal P:C is above average.

Nutrient regulation of primary production of phytoplankton (flagellates and cyanobacteria):

$$fnut(N,P)_{pm} = \frac{2}{\frac{1}{f(N)_{pm}} + \frac{1}{f(P)_{pm}}} \tag{3.10}$$

In the expression for diatoms Si is included:

$$fnut(N,P,Si)_{pm} = \frac{3}{\frac{1}{f(N)_{pm}} + \frac{1}{f(P)_{pm}} + \frac{1}{f(Si)_{pm}}} \tag{3.11}$$

Droop kinetics used for N modified after (Nyholm1978, Nyholm 1979) is used to regulate growth of phytoplankton:

$$f(N)_{pm} = \frac{\frac{PN}{PC} - PNmin}{PNmax - PNmin} \tag{3.12}$$

The same formulation is used for diatoms.

Droop kinetics used for P modified after (Nyholm1978, Nyholm 1979) is used to regulate growth of phytoplankton:

$$f(P)_{pm} = \frac{\left(\frac{PP}{PC} - PPmin\right) * (Kc + PPmax - PPmin)}{(PPmax - PPmin) * (Kc + \frac{PP}{PC} - PPmin)} \tag{3.13}$$

Where:

Name	Comment	Unit
PC	Phytoplankton C	g C m-3
PN	Phytoplankton N	g N m-3
PP	Phytoplankton P	g P m-3
PNmin	Minimum N:C ratio for phytoplankton	g N g C-1
PNmax	Maximum N:C ratio for phytoplankton	g N g C-1
PPmin	Minimum P:C ratio for phytoplankton	g P g C-1
PPmax	Maximum P:C ratio for phytoplankton	g P g C-1

3.3 Differential equations pelagic state variables

3.3.1 PC1: Flagellate C, g C m^{-3}

$$dPC1/dt = PRPC1 - GRPC1 - DEPC1 - SEPC1 - BUOYC1 \tag{3.14}$$

Where:

Process	Comment	Unit
PRPC1	Net production flagellate carbon	g C m^{-3} d^{-1}
GRPC1	Grazing of flagellate carbon	g C m^{-3} d^{-1}
DEPC1	Death of flagellate carbon	g C m^{-3} d^{-1}
SEPC1	Settling of flagellate carbon	g C m^{-3} d^{-1}
BUOYC	Flagellate upward movement	g C m^{-3} d^{-1}

PRPC1: Net Production flagellate carbon, g C m^{-3} d^{-1}

$$PRPC1 = mntp1 * myfi1 * fac * rd * PC1 \tag{3.15}$$

Where:

Name	Comment	Unit	Type*)
mntp1	N, P & temperature corrected max. net growth rate	d^{-1}	A
myfi1	Light function Flagellate,	n.u.	A
fac	Phytoplankton, Correction for dark reaction	n.u.	C
rd	Relative daylength, f(latitude, day,month,year)	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process,
A: Auxiliary help process.

GRPC1: Grazing of phytoplankton (Flagellate) carbon, g C $m^{-3}d^{-1}$

$$GRPC1 = \frac{kedib1 * MAX(PC1 - 0.001)}{MAX(0.001, kedib1 * PC1 + kedib2 * PC2 + kedib3 * PC3)} * mgpc * zc \tag{3.16}$$

Where:

Name	Comment	Unit	Type*)
Kedib1	Edible fraction of Flagellate	n.u.	C
Kedib2	Edible fraction of Diatoms	n.u.	C
Kedib3	Edible fraction of Cyanobacteria	n.u.	C
PC1	Flagellate C	g C m^{-3}	S
PC2	Diatom C	g C m^{-3}	S
PC3	Cyanobacterie C	g C m^{-3}	S
mgpc	Temperature & food corrected grazing rate	d^{-1}	A
ZC	Zooplankton C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

DEPC1: Death of phytoplankton (flagellate) carbon, g C $m^{-3}d^{-1}$

$$DEPC1 = kdma * mnl1 * PC1 \tag{3.17}$$

Where:

Name	Comment	Unit	Type*)
kdma	Specific death rate phytoplankton	d^{-1}	C
mnl1	Nutrient dependent death factor, flagellate	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

SEPC1: Settling of phytoplankton (flagellate) carbon, g C m^{-3}d^{-1}
Phytoflagellates has the ability of vertical movement in the water column optimising their ability to pick up nutrient and gain light. During nutrient limitation the flagellates is assumed to seek down to the pycnocline to pick up nutrient, and in case they are not nutrient limited they are assumed to stay in the photic zone.

In the present model nutrient limitation, in term of a low PN/PC and or PP/PC ratio, enhance the sedimentation rate. PN/PC and PP/PC ratios close to maximum N and P content in the algae result in a reduction of the sedimentation rate. The nutrient regulation of the sedimentation rate is expressed in the auxiliary ***sed1****.*

Light is also regulating the sedimentation rate. At high light dozes the sedimentation is accelerated at medium light dozes sedimentation is ***mspc1*** and at low light dozes the sedimentation decreases. This light regulation is expressed in the auxiliary ***fiz***.

$$SEPC1 = \frac{mspc1}{dz} * sed1 * fiz * PC1 \qquad (3.18)$$

Where:

Name	Comment	Unit	Type*)
mspc1	Sedimentation rate flagellate phytoplankton	m d^{-1}	A
Dz	Height of actual water layer	m	F
sed1	N & P regulation of sedimentation. flagellate	n.u.	A
Fiz	Light factor for PC1 & PC3 sedimentation	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

BUOYC1: Flagellate upward movement, g C m^{-3}d^{-1}
The vertical upward movement by the phytoflagellates is described as a function of light doze and the algae's nutrient condition expressed in the auxiliary *buoy1*. An upward vertical movement is enhanced by a good nutrient condition and a low light doze.

$$BUOYC1 = \frac{mspc1 * buoy1 * PC1}{dz} \qquad (3.19)$$

Where:

Name	Comment	Unit	Type*)
mspc1	Sedimentation rate flagellate phytoplankton	m d^{-1}	A
buoy1	N & P & light upward movement function, flagellate	n.u.	A
Dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.2 PC2: Diatom C, g C m^{-3}

$$\frac{dPC2}{dt} = PRPC2 + GRPC2 - DEPC2 - SEPC2 \tag{3.20}$$

Where:

Process	Comment	Unit
PRPC2	Net production diatom carbon	g C m^{-3} d^{-1}
GRPC2	Grazing of diatom carbon	g C m^{-3} d^{-1}
DEPC2	Death of diatom carbon	g C m^{-3} d^{-1}
SEPC2	Settling of diatom carbon	g C m^{-3} d^{-1}

PRPC2: Net Production phytoplankton carbon, g C m^{-3}d^{-1}

$$PRPC2 = mntp2 * myfi * fac * rd * PC2 \tag{3.21}$$

Where:

Name	Comment	Unit	Type*)
mntp2	N, P, Si & temperature corrected max. net growth rate	d^{-1}	A
myfi2	Light function Diatom	n.u.	A
fac	Phytoplankton, correction for dark reaction	n.u.	C
rd	Relative daylength, f(latitude, day,month,year)	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

GRPC2: Grazing of phytoplankton (Diatom) carbon, g C $m^{-3}d^{-1}$

$$GRPC2 = \frac{kedib2 * MAX(PC2 - 0.001)}{MAX(0.001, kedib1 * PC1 + kedib2 * PC2 + kedib3 * PC3)} * mgpc * zc \tag{3.22}$$

Where:

Name	Comment	Unit	Type*)
Kedib1	Edible fraction of Flagellate	n.u.	C
Kedib2	Edible fraction of Diatoms	n.u.	C
Kedib3	Edible fraction of Cyanobacteria	n.u.	C
PC1	Flagellate C	g C m^{-3}	S
PC2	Diatom C	g C m^{-3}	S
PC3	Cyanobacterie C	g C m^{-3}	S
mgpc	Temperature & food corrected grazing rate	d^{-1}	A
ZC	Zooplankton C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

DEPC2: Death of diatom carbon, g C $m^{-3}d^{-1}$

$$DEPC2 = kdma * mnl2 * PC2 \tag{3.23}$$

Where:

Name	Comment	Unit	Type*)
kdma	Specific death rate phytoplankton	d^{-1}	C
mnl2	Nutrient dependent death factor, diatom	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

SEPC2: Settling ofdiatom carbon, g C $m^{-3}d^{-1}$

$$SEPC2 = mspc2 * \frac{mnl2}{dz} * PC2 \qquad (3.24)$$

Where:

Name	Comment	Unit	Type*)
mspc2	Sedimentation rate diatom phytoplankton	m d^{-1}	A
mnl2	Nutrient function, sedimentation & death, diatom	n.u.	A
dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.3 PC3: Cyanobacteria C, g C m^{-3}

$$dPC3/dt = PRPC3 - GRPC3 - DEPC3 - SEPC3 - BUOYC3 \qquad (3.25)$$

Where:

Process	Comment	Unit
PRPC3	Net production cyanobacteria carbon	g C m-3 d-1
GRPC3	Grazing of cyanobacteria carbon	g C m-3 d-1
DEPC3	Death of cyanobacteria carbon	g C m-3 d-1
SEPC3	Settling of cyanobacteria carbon	g C m-3 d-1
BUOYC3	Cyanobacteria upward movement	g C m-3 d-1

PRPC3: Net Production cyanobacteria carbon, g C $m^{-3}d^{-1}$

$$PRPC3 = mntp3 * myfi3 * fp3sal * fac * rd * PC3 \qquad (3.26)$$

Where:

Name	Comment	Unit	Type*)
mntp3	N, P & temperature corrected max. net growth rate	d^{-1}	A
myfi3	Light function Cyanobacteria,	n.u.	A
fp3sal	Function for cyanobacteria dependency of salinity	n.u.	A
fac	Cyanobacteria, Correction for dark reaction	n.u.	C
rd	Relative daylength, f(latitude, day,month,year)	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

GRPC3: Grazing of cyanobacteria (Flagellate) carbon, g C $m^{-3}d^{-1}$

$$GRPC3 = \frac{kedib3 * MAX(PC3 - 0.001)}{MAX(0.001, kedib1 * PC1 + kedib2 * PC2 + kedib3 * PC3)} * mgpc * zc \qquad (3.27)$$

Where:

Name	Comment	Unit	Type*)
Kedib1	Edible fraction of Cyanobacteria	n.u.	C
Kedib2	Edible fraction of Diatoms	n.u.	C
Kedib3	Edible fraction of Cyanobacteria	n.u.	C
PC1	Flagellate C	g C m^{-3}	S
PC2	Diatom C	g C m^{-3}	S
PC3	Cyanobacteria C	g C m^{-3}	S
mgpc	Temperature & food corrected grazing rate	d^{-1}	A
ZC	Zooplankton C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

DEPC3: Death of cyanobacteria carbon, g C $m^{-3}d^{-1}$

$$DEPC3 = kdma * \frac{mnl3}{fp3sal} * PC3 \tag{3.28}$$

Where:

Name	Comment	Unit	Type*)
kdma	Specific death rate cyanobacteria	d^{-1}	C
mnl3	Nutrient dependent death factor, cyanobacteria	n.u.	A
fp3sal	Function for cyanobacteria dependency of salinity	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

SEPC3: Settling of cyanobacteria carbon, g C $m^{-3}d^{-1}$

Cyanobacteria has the ability of vertical movement in the water column optimising their ability to pick up nutrient and gain light. During nutrient limitation the cyanobacteria seek down to the pycnocline to pick up P nutrients, and in case they are not nutrient limited (P) they are assumed to stay in the photic zone.

In the present model nutrient limitation, in term of a low PN/PC and or PP/PC ratio, enhance the sedimentation rate. PN/PC and PP/PC ratios close to maximum N and P content in the algae result in a reduction of the sedimentation rate. The nutrient regulation of the sedimentation rate is expressed in the auxiliary ***sed3.***

Light is also regulating the sedimentation rate. At high light dozes the sedimentation is accelerated at medium light dozes sedimentation is ***mspc3*** and at low light dozes the sedimentation decreases. This light regulation is expressed in the auxiliary ***fiz***.

$$SEPC3 = \frac{mspc3}{dz} * sed3 * fiz * PC3 \tag{3.29}$$

Where:

Name	Comment	Unit	Type*)
mspc3	Sedimentation rate cyanobacteria	$m\ d^{-1}$	A
Dz	Height of actual water layer	m	F
sed3	N & P regulation of sedimentation. cyanobacteria	n.u.	A
Fiz	Light factor for PC1 & PC3 sedimentation	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

BUOYC3: Cyanobacteria upward movement, g C m^{-3}d^{-1}
The vertical upward movement by the cyanobacteria is described as a function of light doze and the algae's nutrient condition expressed in the auxiliary ***buoy3***. An upward vertical movement is enhanced by a good nutrient condition and a low light doze.

$$BUOYC3 = \frac{mspc3 * buoy3 * PC3}{dz} \tag{3.30}$$

Where:

Name	Comment	Unit	Type*)
mspc3	Sedimentation rate cyanobacteria	d^{-1}	A
Buoy3	N & P & light upward movement function, cyanobacteria	n.u.	A
dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.4 PN1: Flagellate N, g N m^{-3}

$$\frac{dPN1}{dt} = UPNH1 + UPN31 - GRPN1 - DEPN1 - SEPN1 - BUOYN1 \tag{3.31}$$

Where:

Process	Comment	Unit
UPNH1	Uptake of NH_4 into flagellates N	g N m^{-3} d^{-1}
UPN31	Uptake of NO_3 into flagellates N	g N m^{-3} d^{-1}
GRPN1	Grazing of flagellates N	g N m^{-3} d^{-1}
DEPN1	Death of flagellates N	g N m^{-3} d^{-1}
SEPN1	Settling of flagellates N	g N m^{-3} d^{-1}
BUOYN1	Upward movement flagellate N	g N m^{-3} d^{-1}

UPNH1: Uptake of NH_4 into flagellate N, g N m^{-3} d^{-1}

$$UPNH1 = MIN(unh1, pnma * PRPC1) \tag{3.32}$$

UPN31: Uptake of NO_3 into flagellate N, g N m^{-3} d^{-1}

$$UPN31 = MAX(0, MIN(un31, pnma * PRPC1 - UPNH1)) \tag{3.33}$$

GRPN1: Grazing of flagellate N, g N m^{-3} d^{-1}

$$GRPN1 = pn1pc1 * GRPC1 \tag{3.34}$$

DEPN1: Death of flagellate N, g N m^{-3} d^{-1}

$$DEPN1 = pn1pc1 * DEPC1 \tag{3.35}$$

SEPN1: Settling of flagellate N, g N m^{-3} d^{-1}

$$SEPN1 = pn1pc1 * SEPC1 \tag{3.36}$$

BUOYN1: Upward movement of PN1, g N m^{-3} d^{-1}

$$BUOYN1 = pn1pc1 * BUOYC1 \tag{3.37}$$

Where:

Name	Comment	Unit	Type*)
pnma	Max. intracellular algae N	g N g C $^{-1}$	C
unh1	potential NH_4 uptake by flagellate	g N m^{-3} d^{-1}	A
un31	potential NO_3 uptake by flagellate	g N m^{-3} d^{-1}	A
pn1pc1	Flagellate N:C ration	g N g C^{-1}	A
PC1	Flagellate C	g C m^{-3}	S
GRPC1	Grazing of flagellate C	g C m^{-3} d^{-1}	P
DEPC1	Death of flagellate C	g C m^{-3} d^{-1}	P
SEPC1	Settling of flagellate C	g C m^{-3} d^{-1}	P
BUOYC1	Upwared movement of flagellate C	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.5 PN2, Diatom N, g N m^{-3}

$$\frac{dPN2}{dt} = UPNH2 + UPN32 - GRPN2 - DEPN2 - SEPN2 \tag{3.38}$$

Where:

Process	Comment	Unit
UPNH2	Uptake of NH_4 into diatoms N	g N m^{-3} d^{-1}
UPN32	Uptake of NO_3 into diatoms N	g N m^{-3} d^{-1}
GRPN2	Grazing of diatoms N	g N m^{-3} d^{-1}
DEPN2	Death of diatoms N	g N m^{-3} d^{-1}
SEPN2	Settling of diatoms N	g N m^{-3} d^{-1}

UPNH2: Uptake of NH_4 into diatom N, g N m^{-3} d^{-1}

$$UPNH2 = MIN(unh2, pnma * PRPC2) \tag{3.39}$$

UPN32: Uptake of NO_3 into diatom N, g N m^{-3} d^{-1}

$$UPN32 = MAX(0, MIN(un32, pnma * PRPC2 - UPNH2)) \tag{3.40}$$

GRPN2: Grazing of dioatom N, g N m^{-3} d^{-1}

$$GRPN2 = pn2pc2 * GRPC2 \tag{3.41}$$

DEPN2: Death of diatom N, g N m^{-3} d^{-1}

$$DEPN2 = pn2pc2 * DEPC2 \tag{3.42}$$

SEPN2: Settling ofdiatom N, g N m^{-3} d^{-1}

$$SEPN2 = pn2pc2 * SEPC2 \tag{3.43}$$

Where:

Name	Comment	Unit	Type*)
pnma	Max. intracellular algae N	g N g C $^{-1}$	C
unh2	potential NH_4 uptake by diatom	g N m^{-3} d^{-1}	A
un32	potential NO_3 uptake by diatom	g N m^{-3} d^{-1}	A
pn2pc2	Diatom N:C ration	g N g C^{-1}	A
PC2	Diatom C	g C m^{-3}	S
GRPC2	Grazing of diatom C	g C m^{-3} d^{-1}	P
DEPC2	Death of diatom C	g C m^{-3} d^{-1}	P
SEPC2	Settling of diatom C	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.6 PN3, Cyanobacteria N, g N m^{-3}

$$\frac{dPN3}{dt} = UPNH3 + UPN33 + NFIX - GRPN3 - DEPN3 - SEPN3 - BUOYN3 \quad (3.44)$$

Where:

Process	Comment	Unit
UPNH3	Uptake of NH_4 into cyanobacteria N	g N m^{-3} d^{-1}
UPN33	Uptake of NO_3 into cyanobacteria N	g N m^{-3} d^{-1}
NFIX	N fixation cyanobacteria	g N m^{-3} d^{-1}
GRPN3	Grazing of cyanobacteria N	g N m^{-3} d^{-1}
DEPN3	Death of cyanobacterias N	g N m^{-3} d^{-1}
SEPN3	Settling of cyanobacterias N	g N m^{-3} d^{-1}
BUOYN3	Upward movement cyanobacteria N	g N m^{-3} d^{-1}

UPNH3: Uptake of NH4 into cyanobacteria N, g N m^{-3} d-^{1}

$$UPNH3 = MIN(unh3, pnma * PRPC3) \quad (3.45)$$

UPN33: Uptake of NO3 into cyanobacteria N, g N m^{-3} d-^{1}

$$UPN33 = MAX(0, MIN(un33, pnma * PRPC3 - UPNH3)) \tag{3.46}$$

NFIX: N fixation by cyanobacteria N, g N m^{-3} d-^{1}

$$NFIX = IF\ (krednc - pn3pc3) < epsi\ THEN\ 0\ ELSE \\ knfix1 * tppc^{T-20} * \frac{MAX(0, krednp - pn3pc3)}{MAX(0, krednp - pn3pc3) + kqppn} * nfix1 * nfix2 \tag{3.47}$$

GRPN3: Grazing of cyanobacteria N, g N m^{-3} d-^{1}

$$GRPN3 = pn3pc3 * GRPC3 \tag{3.48}$$

DEPN3: Death of cyanobacteria N, g N m^{-3} d-^{1}

$$DEPN3 = pn3pc3 * DEPC3 \tag{3.49}$$

SEPN3: Settling of cyanobacteria N, g N m^{-3} d-^{1}

$$SEPN3 = pn3pc3 * SEPC3 \tag{3.50}$$

BUOYN3: Upward movement of PN3, g N m^{-3} d-^{1}

$$BUOYN3 = pn3pc3 * BUOYC3 \tag{3.51}$$

Where:

Name	Comment	Unit	Type*)
Pnma	Max. intracellular algae N	g N g C $^{-1}$	C
unh3	potential NH$_4$ uptake by cyanobacteria	g N m^{-3} d^{-1}	A
un33	potential NO$_3$ uptake by cyanobacteria	g N m^{-3} d^{-1}	A
pn3pc3	Cyanobacteria N:C ration	g N g C^{-1}	A
krednc	Redfield ratio N:C	g N g C^{-1}	C
knfix1	Max. N fixation, 20 °C, cyanobacteria	g N g C^{-1}d^{-1}	C
Tppc	ϴ in Arrhenius temperature function	n.u.	C
T	Temperature	°C	F
Kqppn	Half saturation constant, N fixation	g N g C^{-1}	C
nfix1	Function for N fixation (1 if PSU≤12 else 0)	n.u.	A

Name	Comment	Unit	Type*)
nfix2	Function for N fixation (1 if 0≤PSU≤10 else 0-1)	n.u.	A
PC3	Cyanobacteria C	g C m^{-3}	S
GRPC3	Grazing of cyanobacteria C	g C m^{-3} d^{-1}	P
DEPC3	Death of cyanobacteria C	g C m^{-3} d^{-1}	P
SEPC3	Settling of cyanobacteria C	g C m^{-3} d^{-1}	P
BUOYC3	Upwared movement of cyanobacteria C	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.7 PP1, Flagellate P, g P m^{-3}

$$\frac{dPP1}{dt} = UPPP1 - GRPP1 - DEPP1 - SEPP1 - BUOYP1 \tag{3.52}$$

Where:

Process	Comment	Unit
UPPP1	Uptake of PO_4 into flagellates P	g P m^{-3} d^{-1}
GRPP1	Grazing of flagellates P	g P m^{-3} d^{-1}
DEPP1	Death of flagellates P	g P m^{-3} d^{-1}
SEPP1	Settling of flagellates P	g P m^{-3} d^{-1}
BUOYP1	Upward movement flagellate	g P m^{-3} d^{-1}

UPPP1: Uptake of PO4 into flagellate P, g P m^{-3} d-^{1}

$$UPPP1 = MIN(upo1, ppma * PRPC1) \tag{3.53}$$

GRPP1: Grazing of flagellate P, g P m^{-3} d-^{1}

$$GRPP1 = pp1pc1 * GRPC1 \tag{3.54}$$

DEPP1: Death of flagellate P, g P m^{-3} d^{-1}

$$DEPP1 = pp1pc1 * DEPC1 \tag{3.55}$$

SEPP1: Settling of flagellate P, g P m^{-3} d^{-1}

$$SEPP1 = pp1pc1 * SEPC1 \tag{3.56}$$

BUOYP1: Upward movement of PP1, g P m^{-3} d^{-1}

$$BUOYP1 = pp1pc1 * BUOYC1 \tag{3.57}$$

Where:

Name	Comment	Unit	Type*)
pnma	Max. intracellular algae P	g P g C $^{-1}$	C
upo1	Potential PO$_4$ uptake by flagellate	g P m^{-3} d^{-1}	A
pp1pc1	Flagellate P:C ration	g P g C^{-1}	A
PC1	Flagellate C	g C m^{-3}	S
GRPC1	Grazing of flagellate C	g C m^{-3} d^{-1}	P
DEPC1	Death of flagellate C	g C m^{-3} d^{-1}	P
SEPC1	Settling of flagellate C	g C m^{-3} d^{-1}	P
BUOYC1	Upward movement of flagellate C	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.8 PP2, Diatom P, g P m^{-3}

$$\frac{dPP2}{dt} = UPPP2 - GRPP2 - DEPP2 - SEPP2 \tag{3.58}$$

Where:

Process	Comment	Unit
UPPP2	Uptake of PO$_4$ into diatoms P	g P m^{-3} d^{-1}
GRPP2	Grazing of diatoms P	g P m^{-3} d^{-1}
DEPP2	Death of diatoms P	g P m^{-3} d^{-1}
SEPP2	Settling of diatoms P	g P m^{-3} d^{-1}

UPPP2: Uptake of PO4 into diatom P, g P g P m^{-3} d^{-1}

$$UPPP2 = MIN(upo2, ppma * PRPC2) \tag{3.59}$$

GRPP2: Grazing of diatom P, g P m^{-3} d^{-1}

$$GRPP2 = pp2pc2 * GRPC2 \tag{3.60}$$

DEPP2: Death of diatom P, g P m^{-3} d^{-1}

$$DEPP2 = pp2pc2 * DEPC2 \tag{3.61}$$

SEPP2: Settling of diatom P, g P m^{-3} d^{-1}

$$SEPP2 = pp2pc2 * SEPC2 \tag{3.62}$$

Where:

Name	Comment	Unit	Type*)
pnma	Max. intracellular algae P	g P g C $^{-1}$	C
upo2	Potential PO_4 uptake by diatom	g P m^{-3} d^{-1}	A
pp2pc2	Diatom P:C ration	g P g C^{-1}	A
PC2	Diatom C	g C m^{-3}	S
GRPC2	Grazing of diatom C	g C m^{-3} d^{-1}	P
DEPC2	Death of diatom C	g C m^{-3} d^{-1}	P
SEPC2	Settling of diatom C	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.9 PP3, Cyanobacteria P, g P m^{-3}

$$\frac{dPP3}{dt} = UPPP3 + UPLDOPP3 - GRPP3 - DEPP3 - SEPP3 - BUOYP3 \tag{3.63}$$

Where:

Process	Comment	Unit
UPPP3	Uptake of PO_4 into cyanobacteria P	g P m^{-3} d^{-1}
UPLDOPP3	Cyanobacteria uptake of LDOP	g P m^{-3} d^{-1}
GRPP3	Grazing of cyanobacteria P	g P m^{-3} d^{-1}
DEPP3	Death of cyanobacteria P	g P m^{-3} d^{-1}
SEPP3	Settling of cyanobacteria P	g P m^{-3} d^{-1}
BUOYP3	Upward movement cyanobacteria	g P m^{-3} d^{-1}

UPPP3: Uptake of PO_4 into cyanobacteria P, g P m^{-3} d^{-1}

$$UPPP3 = MIN(upo3, ppma * PRPC3) \tag{3.64}$$

UPLDOPP3: Cyanobacteria uptake of LDOP, g P m^{-3} d^{-1}

$$\begin{gathered}UPLDOPP3 = IF\ PO4 < 0.001\ THEN \\ IF\ (\left(ppma - \frac{PP3}{PC3}\right) < epsi, 0, maxupip * pda3 * 0.1 * \frac{LDOP}{(LDOP + hupp * pdb3 * 0.1)} * PC3) \\ ELSE\ 0\end{gathered} \tag{3.65}$$

GRPP3: Grazing of cyanobacteria P, g P m^{-3} d^{-1}

$$GRPP3 = pp3pc3 * GRPC3 \tag{3.66}$$

DEPP3: Death of cyanobacteria P, g P m^{-3} d^{-1}

$$DEPP3 = pp3pc3 * DEPC3 \tag{3.67}$$

SEPP3: Settling of cyanobacteria P, g P m^{-3} d^{-1}

$$SEPP3 = pp3pc3 * SEPC3 \tag{3.68}$$

BUOYP3: Upward movement of PP3, g P m^{-3} d^{-1}

$$BUOYP3 = pp3pc3 * BUOYC3 \tag{3.69}$$

Where:

Name	Comment	Unit	Type*)
ppma	Max. intracellular algae P	g P g C^{-1}	C
upo3	Potential PO_4 uptake by cyanobacteria	g P m^{-3} d^{-1}	A
epsi	Small value	n.u.	C
maxupip	Max. PO_4 uptake by flagellates during P	g P g C^{-1}	C
LDOP	Labile DOP	g P m^{-3}	S
pda3	Ratio, nutrient uptake cyanobacteria:flagellates	n.u.	A
pdb3	Halfsaturation conc. Cyanobacteria:flagellates	n.u.	A
pp3pc3	Cyanobacteria P:C ratio	g P g C^{-1}	A
PC3	Cyanobacteria C	g C m^{-3}	S
PP3	Cyanobacteria P	g C m^{-3}	S
GRPC3	Grazing of cyanobacteria C	g C m^{-3} d^{-1}	P
DEPC3	Death of cyanobacteria C	g C m^{-3} d^{-1}	P
SEPC3	Settling of cyanobacteria C	g C m^{-3} d^{-1}	P
BUOYC3	Upwared movement of cyanobacteria C	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.10 PSi2, Diatom Si, g Si m^{-3}

$$\frac{dPSi2}{dt} = UPSi2 - GRPSi2 - DEPSi2 - SEPSi2 \tag{3.70}$$

Where:

Process	Comment	Unit
UPSi2	Uptake of Si into diatoms Si	g Si m^{-3} d^{-1}
GRPSi2	Grazing of diatoms Si	g Si m^{-3} d^{-1}
DEPSi2	Death of diatoms Si	g Si m^{-3} d^{-1}
SEPSi2	Settling of diatoms Si	g Si m^{-3} d^{-1}

UPSi2: Uptake of Si into diatom Si, g Si m^{-3} d^{-1}

$$UPSi2 = MIN(upsi, psma * PRPC2) \tag{3.71}$$

GRPSi2: Grazing of diatomSiP, g Si m^{-3} d^{-1}

$$GRPSi2 = psi2pc2 * GRPC2 \tag{3.72}$$

DEPSi2: Death of diatom Si, g Si m^{-3} d^{-1}

$$DEPSi2 = psi2pc2 * DEPC2 \tag{3.73}$$

SEPSi2: Settling of diatom Si, g Si m^{-3} d^{-1}

$$SEPSi2 = psi2pc2 * SEPC2 \tag{3.74}$$

Where:

Name	Comment	Unit	Type*)
psma	Max. intracellular algae Si	g Si g C^{-1}	C
usi2	potential Si uptake by diatom	g Si m^{-3} d^{-1}	A
psi2pc2	Diatom Si:C ration	Si P g C^{-1}	A
PC2	Diatom C	g C m^{-3}	S
GRPC2	Grazing of diatom C	g C m^{-3} d^{-1}	P
DEPC2	Death of diatom C	g C m^{-3} d^{-1}	P
SEPC2	Settling of diatom C	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.11 CH, Chlorophyll, g m^{-3}

$$\frac{dCH}{dt} = PRCH - DECH - SECH - BUOYCH - GRCH \tag{3.75}$$

Where:

Process	Comment	Unit
PRCH	Net production phytoplankton chlorophyll	g Chl m^{-3} d^{-1}
SECH	Settling of phytoplankton chlorophyll	g Chl m^{-3} d^{-1}
DECH	Death of phytoplankton chlorophyll	g Chl m^{-3} d^{-1}
BUOYCH	Upward movement of CH	g Chl m^{-3} d^{-1}
GRCH	Zooplankton grazing on CH	g Chl m^{-3} d^{-1}

PRCH: Net production phytoplankton chlorophyll, g Chl m^{-3} d^{-1}

The production of chlorophyll

$$PRCH = PRPC1 * \frac{chmi}{ik1} * e^{chma*myn1} + PRPC2 * \frac{chmi}{ik2} * e^{chma*myn2} + PRPC3 * \frac{chmi}{ik1} * e^{chma*myn3} \tag{3.76}$$

SECH: Settling of phytoplankton chlorophyll, g Chl m^{-3} d^{-1}

$$SECH = \frac{CH}{PC1 + PC2 + PC3} * (SEPC1 + SEPC2 + SEPC3) \tag{3.77}$$

DECH: Death of phytoplankton chlorophyll, g Chl m^{-3} d^{-1}

$$DECH = \frac{CH}{PC1 + PC2 + PC3} * (DEPC1 + DEPC2 + DEPC3) \tag{3.78}$$

GRCH: ZC Grazing on CH, g Chl m^{-3} d^{-1}

$$GRCH = \frac{CH}{PC1 + PC2 + PC3} * (GRPC1 + GRPC2 + GRPC3) \tag{3.79}$$

Where:

Name	**Comment**	**Unit**	**Type*)**
PC1	Flagellate C	g C m^{-3}	S
PC2	Diatom C	g C m^{-3}	S
PC3	Cyanobacteria C	g C m^{-3}	S
chmi	Min. chlorophyll-a production	mol $photon^{-1}m^{-2}d^{-1}$	C
chma	Max. chlorophyll-a producti	mol $photon^{-1}m^{-2}d^{-1}$	C
myn1	Nitrogen function Flagellate	n.u.	A
myn2	Nitrogen function Diatom	n.u.	A
myn2	Nitrogen function Cyanobacteria	n.u.	A
ik1	Light saturation temp. corrected, PC1, PC3	mol photon $m^{-2}d^{-1}$	A
Ik2	Light saturation temp. corrected, PC2	mol photon $m^{-2}d^{-1}$	A
PRPC1	Net production of flagellate C	g C m^{-3} d^{-1}	P
SEPC1	Sedimentation of flagellate C	g C m^{-3} d^{-1}	P
DEPC1	Death of flagellate C	g C m^{-3} d^{-1}	P
GRPC1	Grazing of flagellate C	g C m^{-3} d^{-1}	P
PRPC2	Net production of diatom C	g C m^{-3} d^{-1}	P
SEPC2	Sedimentation of diatom C	g C m^{-3} d^{-1}	P
DEPC2	Death of diatom C	g C m^{-3} d^{-1}	P
GRPC2	Grazing of diatom C	g C m^{-3} d^{-1}	P
PRPC3	Net production of cyanobacteria C	g C m^{-3} d^{-1}	P
SEPC3	Sedimentation of cyanobacteria C	g C m^{-3} d^{-1}	P
DEPC3	Death of cyanobacteria C	g C m^{-3} d^{-1}	P
GRPC3	Grazing of cyanobacteria C	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.12 ZC, zooplankton, g C m^{-3}

$$\frac{dZC}{dt} = PRZC - DEZC \tag{3.80}$$

Where:

Process	Comment	Unit
PRZC	Net production of zooplankton carbon	g C m^{-3} d^{-1}
DEZC	Death of zooplankton carbon	g C m^{-3} d^{-1}

PRZC: Production of zooplankton carbon, g C m^{-3} d^{-1}

$$PRZC = vefo * (GRPC1 + GRPC2 + GRPC3) \tag{3.81}$$

DEZC: Death of zooplankton carbon, g C m^{-3} d^{-1}

$$DEZC = kdz * zc^2 + kdzb * zc \tag{3.82}$$

Where:

Name	Comment	Unit	Type*)
vefo	Zooplankton growth efficiency	g C g C^{-1}	C
kdz	Zooplankton death rate 2nd order,	m^3 (g C*d)$^{-1}$	C
kdzb	Zooplankton death rate 1st order	d^{-1}	C
GRPC1	Grazing of flagellate C	g C m^{-3} d^{-1}	P
GRPC2	Grazing of diatom C	g C m^{-3} d^{-1}	P
GRPC3	Grazing of cyanobacteria C	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.13 DC, Detritus C, g C m^{-3}

$$\frac{dDC}{dt} = EKZC + DEZC + DEPC2DC - REDC - deDCw - SREDC - SEDC \tag{3.83}$$

Where:

Process	Comment	Unit
EKZC	Excretion by zooplankton carbon	g C m^{-3} d^{-1}
DEZC	Death of zooplankton carbon	g C m^{-3} d^{-1}
DEPC2DC	Death phytoplankton to detritus carbon	g C m^{-3} d^{-1}
REDC	DO mineralisation of detritus carbon	g C m^{-3} d^{-1}
deDCw	DC anaerobic respiration with NO$_3$	g C m^{-3} d^{-1}
SREDC	DC anaerobic oxidation with SO$_4$	g C m^{-3} d^{-1}
SEDC	Settling of detritus carbon	g C m^{-3} d^{-1}

EKZC: Excretion by zooplankton carbon, g C m^{-3} d^{-1}

$$EKZC = (1 - vefo - refo) * (GRPC1 + GRPC2 + GRPC3) \tag{3.84}$$

DEZC: Death of zooplankton carbon, g C m^{-3} d^{-1}

DEZC: see processes for zooplankton C, ZC, Equation (3.82)

DEPC2DC: Death phytoplankton to detritus carbon, g C m^{-3} d^{-1}

$$DEPC2DC = (1 - vm - vp - vn) * (DEPC1 + DEPC2 + DEPC3) \tag{3.85}$$

REDC: DO mineralisation of detritus carbon, g C m^{-3} d^{-1}

$$EDC = kmdm * DC * tere^{T-20} * \frac{DO^{ndo2}}{MAX(0.01, DO^{ndo2} + mdo2)} \tag{3.86}$$

deDCw: DC respiration with NO$_3$, g C m^{-3} d^{-1}

$$deDCw = (DENW * vn3 + ANAMOX * 0.429) * \frac{DC}{DC + LDOC} \tag{3.87}$$

SREDC: DC oxidation with SO_4, g C m^{-3} d^{-1}

$$sredc = SRED * vso * \frac{dc}{dc + LDOC} \tag{3.88}$$

SEDC: Settling of detritus carbon, g C m^{-3} d^{-1}

$$SEDC = ksd * \frac{dc}{dz} \tag{3.89}$$

Where:

Name	Comment	Unit	Type*)
vefo	Zooplankton growth effency	g C g C^{-1}	C
refo	Zooplankton, respiration	g C g C^{-1}	C
GRPC1	Grazing of flagellate C	g C m^{-3} d^{-1}	P
GRPC2	Grazing of diatom C	g C m^{-3} d^{-1}	P
GRPC3	Grazing of cyanobacteria C	g C m^{-3} d^{-1}	P
DEPC1	Death of flagellate C	g C m^{-3} d^{-1}	P
DEPC2	Death of diatom C	g C m^{-3} d^{-1}	P
DEPC3	Death of cyanobacteria C	g C m^{-3} d^{-1}	P
vm	Fraction of PC mineralised at PC death	n.u.	C
vp	Fraction of PC to CDOC-N&P at PC death	n.u.	C
vn	Fraction of PC to LDOC-N&P at PC death	n.u.	C
kmdm	DC mineralisation rate at 20 ° C	d^{-1}	C
tere	ϴ in Arrhenius function, DC mineralisation	n.u.	C
T	Temperature	°C	F
DO	Oxygen	g O_2 m^{-3}	S
ndo2	DC & LDOC:Coefficient, DO mineralisation	n.u.	C
mdo2	DO half-saturation constant, DC & LDOC mineralisation	n.u	C
DENW	Denitrificaion in water using DC+LDOC	g N m^{-3} d^{-1}	P
vn3	C:N ratio denitrification	g C g N^{-1}	C
ANAMOX	Anammox, NO_3+NH_4 → N_2	g N m^{-3} d^{-1}	P

Name	Comment	Unit	Type*)
LDOC	Labile DOC	g C m^{-3}	S
SRED	SO_4 Respiration of DC+LDOC	g S m^{-3} d^{-1}	P
vso	C:S ratio C mineralisation SO_4 to H_2S	g C g S^{-1}	C
ksd	Sedimentation rate detritus	m d^{-1}	A
dz	Height of actual water layer in model	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.14 DN, Detritus N, g N m^{-3}

$$\frac{dDN}{dt} = EKZN + DEZN + DEPN2DN - REDN - SREDN - deDNw - SEDN \tag{3.90}$$

Where:

Process	Comment	Unit
EKZN	Excretion by zooplankton N	g N m^{-3} d^{-1}
DEZN	Death of zooplankton N	g N m^{-3} d^{-1}
DEPN2DN	Death phytoplankton to detritus N	g N m^{-3} d^{-1}
REDN	DO mineralisation of detritus N to NH_4	g N m^{-3} d^{-1}
deDNw	Anaerobic respiration of DN with NO_3 to NH_4	g N m^{-3} d^{-1}
SREDN	Anaerobic oxidation of DN with SO_4 to NH_4	g N m^{-3} d^{-1}
SEDN	Settling of detritus N	g N m^{-3} d^{-1}

EKZN: Excretion by zooplankton N, g N m^{-3} d^{-1}

$$EKZN = (1 - vefo - refo) * (GRPN1 + GRPN2 + GRPN3) \tag{3.91}$$

DEZN Death of zooplankton N, g N m^{-3} d^{-1}

$$DEZN = vzn * DEZC \tag{3.92}$$

DEPN2DN: Death phytoplankton to detritus N, g N m^{-3} d^{-1}

$$DEPN2DN = (1 - vm - vp - vn) * (DEPN1 + DEPN2 + DEPN3) \tag{3.93}$$

REDN: DO mineralisation of detritus N, g N m^{-3} d^{-1}

$$REDN = kmdn * dndc * REDC \tag{3.94}$$

deDNw: DN respiration with NO3, g N m^{-3} d^{-1}

$$deDNw = deDCw * dndc \tag{3.95}$$

SREDN: DN oxidation with SO4, g N m^{-3} d^{-1}

$$SREDN = SREDC * dndc \tag{3.96}$$

SEDN: Settling of detritus N, g N m^{-3} d^{-1}

$$SEDN = SEDC * dndc \tag{3.97}$$

Where:

Name	Comment	Unit	Type*)
vefo	Zooplankton growth effency	g C g C^{-1}	C
refo	Zooplankton, respiration	g C g C^{-1}	C
GRPN1	Grazing of flagellate N	g N m^{-3} d^{-1}	P
GRPN2	Grazing of diatom N	g N m^{-3} d^{-1}	P
GRPN3	Grazing of cyanobacteria N	g N m^{-3} d^{-1}	P
DEPN1	Death of flagellate N	g N m^{-3} d^{-1}	P
DEPN2	Death of diatom N	g N m^{-3} d^{-1}	P
DEPN3	Death of cyanobacteria N	g N m^{-3} d^{-1}	P
vzn	N:C ratio Zooplankton	g N g C^{-1}	C
vm	Fraction of PC mineralised at PC death	n.u.	C
vp	Fraction of PC to CDOC-N&P at PC death	n.u.	C
vn	Fraction of PC to LDOC-N&P at PC death	n.u.	C
kmdn	Factor N mineralisation of DN	n.u.	C
dndc	N:C ration, detritus	g N g C^{-1}	A
REDC	DO mineralisation of detritus carbon	g C m^{-3} d^{-1}	P

Name	Comment	Unit	Type*)
deDCw	Anaerobic DC respiration with NO_3	g C m^{-3} d^{-1}	P
SREDC	Anaerobic DC oxidation with SO_4	g C m^{-3} d^{-1}	P
SEDC	Settling of detritus carbon	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.15 DP, Detritus P, g P m^{-3}

$$\frac{dDP}{dt} = EKZP + DEZP + DEPP2DP - REDP - SREDP - deDPw - SEDP \tag{3.98}$$

Where:

Process	Comment	Unit
EKZP	Excretion by zooplankton P	g P m^{-3} d^{-1}
DEZP	Death of zooplankton P	g P m^{-3} d^{-1}
DEPP2DNP	Death phytoplankton to detritus P	g P m^{-3} d^{-1}
REDP	DO mineralisation of detritus P to PO_4	g P m^{-3} d^{-1}
deDPw	Anaerobic respiration of DP with NO_3 to PO_4	g P m^{-3} d^{-1}
SREDP	Anaerobic oxidation of DP with SO_4 to PO_4	g P m^{-3} d^{-1}
SEDP	Settling of detritus P	g P m^{-3} d^{-1}

EKZP: Excretion by zooplankton P, g P m^{-3} d^{-1}

$$EKZP = (1 - vefo - refo) * (GRPP1 + GRPP2 + GRPP3) \tag{3.99}$$

DEZP: Death of zooplankton P, g P m^{-3} d^{-1}

$$DEZP = vzp * DEZC \tag{3.100}$$

DEPP2DP: Death phytoplankton to detritus P, g P m^{-3} d^{-1}

$$DEPP2DP = (1 - vm - vp - vn) * (DEPP1 + DEPP2 + DEPP3) \tag{3.101}$$

REDP: DO mineralisation of detritus P, g P m^{-3} d^{-1}

$$REDP = kmdp * dpdc * REDC \tag{3.102}$$

deDPw: DP respiration with NO_3, g P m^{-3} d^{-1}

$$deDPw = deDCw * dpdc \tag{3.103}$$

SREDP: DP oxidation with SO_4, g P m^{-3} d^{-1}

$$SREDP = SREDC * dpdc \tag{3.104}$$

SEDP: Settling of detritus P, g P m^{-3} d^{-1}

$$SEDP = SEDC * dpdc \tag{3.105}$$

Where:

Name	Comment	Unit	Type*)
vefo	Zooplankton growth effency	g C g C^{-1}	C
refo	Zooplankton, respiration	g C g C^{-1}	C
GRPP1	Grazing of flagellate P	g P m^{-3} d^{-1}	P
GRPP2	Grazing of diatom P	g P m^{-3} d^{-1}	P
GRPP3	Grazing of cyanobacteria P	g P m^{-3} d^{-1}	P
DEPP1	Death of flagellate P	g P m^{-3} d^{-1}	P
DEPP2	Death of diatom P	g P m^{-3} d^{-1}	P
DEPP3	Death of cyanobacteria P	g P m^{-3} d^{-1}	P
vzp	P:C ratio Zooplankton	g P g C^{-1}	C
vm	Fraction of PC mineralised at PC death	n.u.	C
vp	Fraction of PC to CDOC-N&P at PC death	n.u.	C
vn	Fraction of PC to LDOC-N&P at PC death	n.u.	C
kmdp	Factor P mineralisation of DP	n.u.	C
dpdc	P:C ration, detritus	g P g C^{-1}	A
REDC	DO mineralisation of detritus carbon	g C m^{-3} d^{-1}	P
deDCw	Anaerobic DC respiration with NO_3	g C m^{-3} d^{-1}	P

Name	Comment	Unit	Type*)
SREDC	Anaerobic DC oxidation with SO_4	g C m^{-3} d^{-1}	P
SEDC	Settling of detritus carbon	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.16 DSi, Detritus Si, g Si m^{-3}

$$\frac{dDSi}{dt} = DEPSi2 + GRPSi2 - REDSi - SEDSi \tag{3.106}$$

Where:

Process	Comment	Unit
DEPSi2	Death phytoplankton Si to detritus Si	g Si m^{-3} d^{-1}
GRPSi2	Grazing of Diatom Si	g Si m^{-3} d^{-1}
REDSi	DO mineralisation of detritus Si to Si	g Si m^{-3} d^{-1}
SEDSi	Settling of detritus Si	g Si m^{-3} d^{-1}

DEPSi2: Death phytoplankton Si to detritus Si, g Si m^{-3} d^{-1}

$$DEPSi2 = DEPC2 * psi2pc2 \tag{3.107}$$

GRPSi2: Grazing of Diatom Si, g Si m^{-3} d^{-1}

$$GRSi2 = GRPC2 * psi2pc2 \tag{3.108}$$

REDSi: DO mineralisation of detritus Si to Si, g Si m^{-3} d^{-1}

$$REDSi = REDC * dsidc * kmds \tag{3.109}$$

SEDSi: Settling of detritus Si, g Si m^{-3} d^{-1}

$$SEDSi = SEDC * dsidc \tag{3.110}$$

Where:

Name	Comment	Unit	Type*)
DEPC2	Death of diatom C	g C m^{-3} d^{-1}	P
psi2pc2	Si:C ration, Diatom	g Si g C^{-1}	A
GRPC2	Grazing of diatom C	g C m^{-3} d^{-1}	P
REDC	DO mineralisation of detritus carbon	g C m^{-3} d^{-1}	P
dsidc	Si:C ration, detritus	g Si g C^{-1}	A
kmds	Factor Si mineralisation of DSi	n.u.	C
SEDC	Settling of detritus carbon	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.17 NH4, Total ammonia, g N m^{-3}

$$\begin{aligned}\frac{dNH4}{dt} = {} & REDN + REZN + deDNw + SREDN + reLDON + deLDON \\ & + sreLDON + feunh4m3 + fsnb + NH4dep + DEPN2NH \\ & - RNIT - ANAMOX - UPNH1 - UPNH2 - UPNH3\end{aligned} \tag{3.111}$$

Where:

Process	Comment	Unit
REDN	DN→NH_4 via DO oxidation of DC	g N m^{-3} d^{-1}
REZN	Respiration of zooplankton nitrogen	g N m^{-3} d^{-1}
deDNw	DN→NH_4 denitrification mineralisation of DC	g N m^{-3} d^{-1}
SREDN	DN →NH_4 via SO_4 mineralisation of DC	g N m^{-3} d^{-1}
reLDON	LDON→NH_4 via DO oxidation of LDOC	g N m^{-3} d^{-1}
deLDON	LDON →NH_4 via denitrification mineralisation of LDOC	g N m^{-3} d^{-1}
sreLDON	LDON →NH_4 via SO_4 mineralisation of LDOC	g N m^{-3} d^{-1}
feunh4m3	NH_4 flux between sediment pore water and water	g N m^{-3} d^{-1}
fsnb	Mineralisation of newly settled organic N	g N m^{-3} d^{-1}
NH4dep	Atmospheric NH_4 deposition	g N m^{-3} d^{-1}
DEPN2NH	Fraction of DEPN1-3 to NH_4	g N m^{-3} d^{-1}

Process	Comment	Unit
RNIT	Nitrification in water column	g N m^{-3} d^{-1}
ANAMOX	Anammox, NO_3+NH_4 → N_2	g NH_4-N m^{-3} d^{-1}
UPNH1	NH_4 uptake by flagellate	g N m^{-3} d^{-1}
UPNH2	NH_4 uptake by diatom	g N m^{-3} d^{-1}
UPNH3	NH_4 uptake by cyanobacteria	g N m^{-3} d^{-1}

REDN: NH4 production via mineralisation of DC, DN & DP with DO, g N m^{-3} d^{-1}

Please see under DN, Equation (3.94)

REZN: Respiration of zooplankton nitrogen, g N m^{-3} d^{-1}

$$REZN = (\mathrm{GRPN1} + \mathrm{GRPN2} + \mathrm{GRPN3}) * vzn - EKZN \quad (3.112)$$

Where: **EKZN: Excretion of N by zooplankton**

$$EKZN = (1 - \mathrm{vefo} - \mathrm{refo}) * (\mathrm{GRPN1} + \mathrm{GRPN2} + \mathrm{GRPN3}) \quad (3.113)$$

deDNw: NH4 production via denitrificatiation (NO3 mineralisation) of DC, DN & DP, g N m^{-3} d^{-1}

Pease see under DN, Equation (3.95)

SREDN: NH4 production via anaerobic SO4 mineralisation of DC, DN & DP, g N m^{-3} d^{-1}
Please see under DN, Equation (3.96)

reLDON: NH4 production via mineralisation of LDOC, LDON & LDOP with DO, g N m^{-3} d^{-1}
Please see under LDON (Section 3.3.27).

deLDON: NH4 production via denitrificatiation, (mineralisation) of LDOC, LDON & LDOP, g N m^{-3} d^{-1}

Please see under LDON (Section 3.3.27).

sreLDON: NH4 production via anaerobic SO4 mineralisation of LDOC, LDON & LDOP, g N m^{-3} d^{-1}

Please see under LDON (Section 3.3.27).

feunh4m3: NH4 flux between sediment pore water and water, g N m^{-3} d^{-1}

$$feunh4m3 = feunh4/dz \tag{3.114}$$

fsnb: Mineralisation of newly settled organic N, g N m^{-3} d^{-1}

$$\begin{aligned} fsnb = krsn0 * (SEPN1 - BUOYN1 + SEPN2 + SEPN3 - BUOYN3 + SEDN \\ - depoC * knim/dz) * tetn^{T-20} \end{aligned} \tag{3.115}$$

NH4dep: Atmospheric N deposition as NH4 to surface layer, g N m^{-3} d^{-1}

$$NH4depo = NHdep/dz \tag{3.116}$$

RNIT: Nitrification in water column, g N m^{-3} d^{-1}

$$RNIT = \mathrm{knitw} * tnit^{T-20} * \mathrm{sqdo} * \frac{NH4}{NH4 + hmt} * \mathrm{NH4} \tag{3.117}$$

ANAMOX: Anammox, NO3+NH4 → N2, , g NH4-N m^{-3} d^{-1}

$$ANAMOX = IF\ DO < 0.32\ THEN$$

$$kanam * tetn^{T-20} * \frac{NH4}{NH4 + hun4} * \frac{NO3}{NO3 + hun3} * \frac{DC + LDOC}{DC + LDOC + hudc1} \tag{3.118}$$

$$ELSE\ 0$$

UPNH1-3: NH4 uptake by phytoplankton, g N m^{-3} d^{-1}

UPNH1, UPNH2 & UPNH3 see under PN1 (Section 3.3.4), PN2 (Section 3.3.5) and PN3 (Section 3.3.6)

Where:

Name	Comment	Unit	Type*)
vzn	N to C ratio in zooplankton,	g N g C^{-1}	C
GRPN1	Grazing of flagellate N	g N m^{-3} d^{-1}	P
GRPN2	Grazing of diatom N	g N m^{-3} d^{-1}	P
GRPN3	Grazing of cyanobacteria N	g N m^{-3} d^{-1}	P
EKZN	Excretion of N by zooplankton	g N m^{-3} d^{-1}	P
vefo	Zooplankton growth effency	g C g C^{-1}	C

Name	Comment	Unit	Type*)
refo	Zooplankton, respiration	g C g C^{-1}	C
feunh4	Flux of NH_4 from sediment to water	g N m^{-2} d^{-1}	P
SEPN1	Settling of flagellate N	g N m^{-3} d^{-1}	P
SEPN2	Settling of diatom N	g N m^{-3} d^{-1}	P
SEPN3	Settling of cyanobacteria N	g N m^{-3} d^{-1}	P
BUOYN1	Upward movement of flagellate N	g N m^{-3} d^{-1}	P
BUOYN3	Upward movement of cyanobacteria N	g N m^{-3} d^{-1}	P
depoC	Deposition of organic C to sediment	g C m^{-2} d^{-1}	P
knim	Sediment: N:C ratio of immobile N	g N g C^{-1}	C
tetn	ϴ value in Arrhenius equation for N	n.u.	C
T	Temperature Deg. Celsius	°C	C
NHdep	Atmospheric N deposition	g N m^{-2} d^{-1}	F
knitw	Specific nitrification water at 20 C	d^{-1}	C
tnit	ϴ value in Arrhenius equation for nitrification	n.u.	C
hmt	Halfsaturation NH_4 nitrification	g N m^{-3} d^{-1}	C
sqdo	DO function	n.u.	A
kanam	max anammox NO_3-N or NH_4-N concumption	g N m^{-3} d^{-1}	C
NO3	NO_3 –N	g N m^{-3}	S
hun4	NH_4 half satutation conc., anammox & thiodenitrification	g N m^{-3}	C
hun3	NO_3 half saturation concentration, anammox	g N m^{-3}	C
DC	Detrituc C	g C m^{-3}	S
LDOC	Labile DOC	g C m^{-3}	S
hudc1	DC+LDC Half saturation concentration, anammox	g C m^{-3}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.18 NO3, Nitrate, g N m^{-3}

$$\frac{dNO3}{dt} = RNIT + feuno3m3 + NO3dep - DENW - DENW_S - ANAMOX - UPN31 - UPN32 - UPN33 \tag{3.119}$$

Where:

Process	Comment	Unit
RNIT	Nitrification in water column	g N m^{-3} d^{-1}
feuno3m3	Flux of NO_3 between water & sediment	g N m^{-3} d^{-1}
NO3dep	Atmospheric deposition of NO_3 at the water surface	g N m^{-3} d^{-1}
DENW	Denirification water	g N m^{-3} d^{-1}
$DENW_s$	Thiodenitification, $4NO_3+3H_2S \rightarrow 2N_2+3SO_4$	g N m^{-3} d^{-1}
ANAMOX	Anammox, $NO_3+NH_4 \rightarrow N_2$	g NO_3-N m^{-3} d^{-1}
UPN31	NO_3 uptake by flagellate	g N m^{-3} d^{-1}
UPN32	NO_3 uptake by diatom	g N m^{-3} d^{-1}
UPN32	NO_3 uptake by cyanobacteria	g N m^{-3} d^{-1}

RNIT: Nitrification in water column, g N m^{-3} d^{-1}

Please see under NH4, Equation (3.117)

feuno3m3: Flux of NO3 between water & sediment, g N m^{-3} d^{-1}

$$feuno3m3 = feuno3/dz \tag{3.120}$$

NO3dep: Atmospheric deposition of NO3 at the water surface, g N m^{-3} d^{-1}

$$NO3dep = NO3depo/dz \tag{3.121}$$

DENW: Denirification water, g N m^{-3} d^{-1}

$$denw = \text{IF } DO < \text{mdo3 THEN}$$

$$kdenw * tetn^{T-20} * \frac{ksb + 0.1}{DO + ksb + 0.1} * \frac{NO3}{NO3 + hun3} * \frac{DC + LDOC}{DC + LDOC + hudc} \tag{3.122}$$

$$\text{ELSE } 0$$

DENWS: Thiodenitification, 4NO3+3H2S→2N2+3SO4, g N m^{-3} d^{-1}

$$DENW_s = IF\ DO < 0.32\ THEN$$

$$kdenw * tetn^{T-20} * \frac{H2S}{H2S + hs1} * \frac{NO3}{NO3 + hun3} * \frac{hudc}{DC + LDOC + hudc} \tag{3.123}$$

$$ELSE\ 0$$

ANAMOX: Anammox, NO3+NH4 → N2 , g NO3-N m^{-3} d^{-1}

$$ANAMOX = IF\ DO < 0.32\ THEN$$

$$kanam * tetn^{T-20} * \frac{NH4}{NH4 + hun4} * \frac{NO3}{NO3 + hun3} * \frac{DC + LDOC}{DC + LDOC + hudc1} \tag{3.124}$$

$$ELSE\ 0$$

UPN31, UPN32, UPN33: NO3 uptake flagellates, diatoms and cyanobacteria, g N m^{-3} d^{-1}

Please see under PN1 (Section 3.3.4), PN2 (Section 3.3.5) and PN3 (Section 3.3.6)

Where:

Name	Comment	Unit	Type*)
feuno3	Nitrate flux between sediment and water column	g N m^{-2} d^{-1}	P
NO3depo	Atmospheric NO_3-N deposition to water surface	g N m^{-2} d^{-1}	F
mdo3	DO limit for denitrification in water column & half saturation concentration in sqdo	g O_2 m^{-3}	C
Kdenw	Max. denitrification at 20 °C in water column	g N m^{-3} d^{-1}	C
ksb	Half saturation DO conc. for denitrification	g O_2 m^{-3}	C
tetn	Θ in Arrhenius function, denitrifications temperature dependency	n.u	C
hun3	NO_3 half saturation concentration for denitrification	g N m^{-3}	C
hudc	DC+LDOC Half saturation concentration for SO_4 reduction & denitrification	g C m^{-3}	C
DC	Detritus C	g C m^{-3}	S
LDOC	Labile fraction of DOC	g C m^{-3}	S
tetn	Θ value in Arrhenius equation for N	n.u.	C

Name	Comment	Unit	Type*)
T	Temperature	°C	F
H2S	H_2S-S	g S m^{-3}	S
hs1	H2S half saturation thiodenitirfication	g S m^{-3}	C
NH4	NH_4-N	g N m^{-3}	S
hun4	NH_4 half satutation conc., anammox & thiodenitrification	g N m^{-3}	C
hudc1	DC+LDC Half saturation concentration, anammox	g C m^{-3}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.19 H2S, Hydrogen Sulphide, g S m^{-3}

$$\frac{dH2S}{dt} = SRED + fwsh2sm3 - SOXI - SOXI_N \tag{3.125}$$

Where:

Process	Comment	Unit
SRED	Anaerobic SO_4 Respiration of DC+LDOC	g S m^{-3} d^{-1}
fwsh2sm3	H_2S flux from sediment to water	g S m^{-3} d^{-1}
SOXI	Oxidation of H_2S	g S m^{-3} d^{-1}
$SOXI_N$	SO_4 production by thiodenitrification, $4NO_3+3H_2S \rightarrow 2N_2+3SO_4$	g S m^{-3} d^{-1}

SRED: SO_4 Respiration of DC+LDOC, g S m^{-3} d^{-1}

$$SRED = IF\ DO < 0.5\ THEN$$

$$ksc * fsa * ts4r^{(T-20)} * \frac{hun3}{NO3 + hun3} * \frac{DC + LDOC}{DC + LDOC + hudc} \tag{3.126}$$

$$ELSE\ 0$$

fwsh2sm3: H_2S flux from sediment to water, g S m^{-3} d^{-1}

$$fwsh2sm3 = fwh2s/dz \tag{3.127}$$

SOXI: Oxidation of H_2S, g S m^{-3} d^{-1}

$$SOXI = kse * ksf^{(T-20)} * H2S * sqdo \tag{3.128}$$

$SOXI_N$: SO_4 production by thiodenitrification, $4NO_3+3H_2S \text{-->} 2N_2+3SO_4$, g S m^{-3} d^{-1}

$$SOXI_N = DENW_S * 1.429 \tag{3.129}$$

Where:

Name	Comment	Unit	Type*)
Ksc	Max. anoxic DC +LDOC respiration rate with SO_4	g S m^{-3} d^{-1}	C
Fsa	Salinity function for reduction of SO4 to H2S	n.u.	A
hun3	NO_3 half saturation concentration for denitrification	g N m^{-3}	C
Hudc	DC+LDOC Half saturation concentration for SO_4 reduction & denitrification	g C m^{-3}	C
DC	Detritus C	g C m^{-3}	S
LDOC	Labile fraction of DOC	g C m^{-3}	S
ts4r	Θ value in Arrhenius function for SO_4 reductions temperature dependency.	n.u.	C
fwh2s	Flux of reduced H_2S equialents from sediment to water	g S $m^{-2}d^{-1}$	P
Kse	Max. specific oxidation rate of H2S, 20 deg. °C	d^{-1}	C
Ksf	Θ value in Arrhenius function for SO_4 oxidations temperature dependency.	n.u.	C
Sqdo	DO function	n.u.	A
$DENW_S$	Thiodenitification. $4NO_3+3H_2S \rightarrow 2N_2+3SO_4$	g N $m^{-3}d^{-1}$	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.20 IP, Phosphate (PO4-P), g P m^{-3}

$$\frac{dIP}{dt} = REDP + REZP + reLDOP + deLDOP + sreLDOP + deDPw + SREDP + DEPP2IP + fspb + fsipm3 + Pdep - UPPP1 - UPPP2 - UPPP3 \tag{3.130}$$

Where:

Process	Comment	Unit
REDP	DP→PO$_4$ via DO oxidation of DC	g P m^{-3} d^{-1}
REZP	Respiration of zooplankton P	g P m^{-3} d^{-1}
reLDOP	LDOP→PO$_4$ via DO oxidation of LDOC	g P m^{-3} d^{-1}
deLDOP	LDOP →PO$_4$ via denitrification mineralisation of LDOC	g P m^{-3} d^{-1}
sreLDOP	LDOP →PO$_4$ via SO$_4$ mineralisation of LDOC	g P m^{-3} d^{-1}
deDPw	DP→PO$_4$ denitrification mineralisation of DC	g P m^{-3} d^{-1}
SREDP	DP →PO$_4$ via SO$_4$ mineralisation of DC	g P m^{-3} d^{-1}
DEPP2IP	Dead Plankton P to PO$_4$	g P m^{-3} d^{-1}
fspb	Mineralisation of newly settled organic P	g P m^{-3} d^{-1}
fsipm3	PO$_4$ flux between sediment pore water and water	g P m^{-3} d^{-1}
Pdep	Atmospheric P deposition	g P m^{-3} d^{-1}
UPPP1	PO$_4$ uptake by flagellates	g P m^{-3} d^{-1}
UPPP2	PO$_4$ uptake by Diatoms	g P m^{-3} d^{-1}
UPPP3	PO$_4$ uptake by cyanobacteria	g P m^{-3} d^{-1}

REDP: PO$_4$ production via mineralisation of DC, DN & DP with DO, g P m^{-3} d^{-1}

Please see under state variable DP, Section 3.3.15

REZP: Respiration of zooplankton phosphorus, g P m^{-3} d^{-1}

$$REZP = \mathrm{MAX}(0, \mathrm{GRPP1} + \mathrm{GRPP2} + \mathrm{GRPP3} - \mathrm{PRZC} * vzp - EKZP) \tag{3.131}$$

reLDOP: PO4 production via mineralisation of LDOC, LDON & LDOP with DO, g P m^{-3} d^{-1}

$$reLDOP = \frac{LDOP}{LDOC} * reLDOC \tag{3.132}$$

deLDOP: PO4 production via denitrificatiation (mineralisation) of LDOC, LDON & LDOP, g P m^{-3} d^{-1}

$$deLDOP = \frac{LDOP}{LDOC} * deLDOC \tag{3.133}$$

sreLDOP: PO4 production via anaerobic SO4 mineralisation of LDOC, LDON & LDOP, g P m^{-3} d^{-1}

$$sreLDOP = \frac{LDOP}{LDOC} * sreLDOC \tag{3.134}$$

deDPw: PO4 production via anaerobic denitrificatiation (mineralisation) of DC, DN & DP, g P m^{-3} d^{-1}

Please see under DP, Section 3.3.15

SREDP: PO4 production via anaerobic SO4 mineralisation of DC, DN & DP, g P m^{-3} d^{-1}

Please see under DP, Section 3.3.15

DEPP2IP: Dead Plankton P to PO4 , g P m^{-3} d^{-1}

$$\mathrm{DEPP2IP} = (\mathrm{DEPP1} + \mathrm{DEPP2} + \mathrm{DEPP3}) * \mathrm{vm} \tag{3.135}$$

fspb: Mineralisation of newly settled organic P, g P m^{-3} d^{-1}

$$\begin{aligned} fspb = krsp0 * (&SEPP1 - BUOYP1 + SEPP2 + SEPP3 - BUOYP3 + SEDP) \\ &* tetp^{T-20} \end{aligned} \tag{3.136}$$

fsipm3: PO4 flux between sediment pore water and water, g P m^{-3} d^{-1}

$$fsipm3 = fsip/dz \tag{3.137}$$

Pdep: Atmospheric P deposition as PO4 to surface layer, g P m^{-3} d^{-1}

$$Pdep = Pdepo/dz \tag{3.138}$$

UPPP1-3: PO4 uptake by flagellates, diatoms and cyanobacteria, g P m^{-3} d^{-1}

Please see under PP1 (Section 3.3.7), PP2 (Section 3.3.8), and PP3 (Section 3.3.9)

Where:

Name	Comment	Unit	Type*)
GRPP1	Grazing of phytoplankton (Flagellate) P	g P m^{-3} d^{-1}	P
GRPP2	Grazing of phytoplankton (diatom) P	g P m^{-3} d^{-1}	P
GRPP3	Grazing of cyanobacteria P	g P m^{-3} d^{-1}	P
PRZC	Net production of zooplankton C	g C m^{-3} d^{-1}	P
vzp	P:C ratio in zooplankton	g P g C^{-1}	C
EKZP	Excretion by zooplankton P	g P m^{-3} d^{-1}	P
reLDOC	DO respiration LDOC	g C m^{-3} d^{-1}	P
LDOP	Labile DOP	g P m^{-3}	S
LDOC	Labile DOC	g C m^{-3}	S
deLDOC	Anaerobic mineralisation of LDOC via denitrification	g C m^{-3} d^{-1}	P
sreLDOC	Anaerobic mineralisation of LDOC via SO_4 reduction	g C m^{-3} d^{-1}	P
DEPP1	Death of flagellate P	g P m^{-3} d^{-1}	P
DEPP2	Death of diatom P	g P m^{-3} d^{-1}	P
DEPP3	Death of cyanobacteria P	g P m^{-3} d^{-1}	P
vm	Fraction of PC mineralised at PC death	n.u.	C
krsp0	Fraction of newly settled P to mineralisation	n.u.	C
SEPP1	Sedimentation of flagellates P	g P m^{-3} d^{-1}	P
SEPP2	Sedimentation of diatom P	g P m^{-3} d^{-1}	P
SEPP3	Sedimentation of cyanobacteria P	g P m^{-3} d^{-1}	P
BUOYP1	Upward movement of flagellates P	g P m^{-3} d^{-1}	P
BUOYP3	Upward movement of cyanobacteria P	g P m^{-3} d^{-1}	P
SEDP	Sedimentation detritus P	g P m^{-3} d^{-1}	P
tetp	Θ value in Arrhenius equation for P	n.u.	C
T	Temperature Deg. Celsius	°C	C
fsip	PO_4 flux between pore water and water	g P m^{-2} d^{-1}	P
Pdep	Atmospheric P deposition	g P m^{-2} d^{-1}	F
dz	Height of actual water layer in model	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.21 IP, Phosphate (PO4-P), g P m^{-3}

$$\frac{dSi}{dt} = REDSi + RSSi2Si - UPSi2 \tag{3.139}$$

Where:

Process	Comment	Unit
REDSi	DO mineralisation of detritus DSi to Si	g Si m^{-3}d^{-1}
RSSi2Si	Si release fom sediment	g Si m^{-3}d^{-1}
UPSi2	Uptake of Si into diatom Si	g Si m^{-3}d^{-1}

DEPSi2: Death phytoplankton Si to detritus Si, g Si m^{-3} d^{-1}

Please see under DSi, Section 3.3.16

RSSi2Si: Si release fom sediment, g Si m^{-3} d^{-1}

$$RSSi2Si = RSSi/dz \tag{3.140}$$

UPSi2: Uptake of Si into diatom Si, g Si Si m^{-3} d^{-1}

Please see under Psi2, Section 3.3.10

Where:

Name	Comment	Unit	Type*)
RSSi	Si release form sediment	g Si m^{-2} d^{-1}	P
dz	Height of actual water layer in model	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.22 DO, Oxygen, g O2 m^{-3}

$$\frac{dDO}{dt} = ODPC + REAR + REAR1 - ODDC - ODZC - SOXI2DO - RNIT2DO - reLDOC2DO - DEPC2DO - ODSC \tag{3.141}$$

Where:

Process	Comment	Unit
ODPC	Net O_2 production by phytoplankton	g O_2 m^{-3} d^{-1}
REAR	Reaeration	g O_2 m^{-3} d^{-1}
REAR1	Reaeration shallow water	g O_2 m^{-3} d^{-1}
ODDC	DO consumption by mineralisation of DC	g O_2 m^{-3} d^{-1}
ODZC	Zooplankton respiration	g O_2 m^{-3} d^{-1}
SOXI2DO	DO consumption due to H_2S oxidation	g O_2 m^{-3} d^{-1}
RNIT2DO	DO consumption due to nitrification	g O_2 m^{-3} d^{-1}
reLDOC2DO	DO consumption by mineralisation of LDOC	g O_2 m^{-3} d^{-1}
DEPC2DO	DO consumption by mineralisation during PC death	g O_2 m^{-3} d^{-1}
ODSC	Sediment DO consumption	g O_2 m^{-3} d^{-1}

ODPC: Net O_2 production/consumption by phytoplankton, g O_2 m^{-3}d^{-1}

$$ODPC = (PRPC1 + PRPC2 + PRPC3) * vo \tag{3.142}$$

REAR: Reaeration, surface layer only, g O_2 m^{-3}d^{-1}

$$REAR = IF\ depth{<}5\ THEN\ 0\ ELSE \\ \left(3.93*\frac{\sqrt{hcur}}{depth^{1.5}} + \frac{2.07+0.215*wsp^{1.7}}{100*24}\right)*(csair\text{-}DO)/dz \tag{3.143}$$

REAR1: Reaeration, shallow water all layers, g O_2 m^{-3}d^{-1}

$$REAR1 = IF\ depth{<}5\ THEN \\ \left(3.93*\frac{\sqrt{hcur}}{MAX(0.1,depth)^{1.5}} + \frac{2.07+0.215*wsp^{1.7}}{100*24}\right)*(csair\text{-}DO)*dz/depth \\ ELSE\ 0 \tag{3.144}$$

ODDC: DO consumption by mineralisation of DC, g O_2 m^{-3}d^{-1}

$$ODDC = REDC * vo \tag{3.145}$$

ODZC: Zooplankton respiration, g O_2 $m^{-3}d^{-1}$

$$ODZC = REZC * vo \tag{3.146}$$

Where:

$$REZC = (GRPC1 + GRPC2 + GRPC3) * refo \tag{3.147}$$

SOXI2DO: DO consumption due to H_2S oxidation, g O_2 $m^{-3}d^{-1}$

$$SOXI2DO = SOXI * vsh \tag{3.148}$$

RNIT2DO: DO consumption due to nitrification, g O_2 $m^{-3}d^{-1}$

$$RNIT2DO = RNIT * vnh \tag{3.149}$$

reLDOC2DO: DO consumption by mineralisation of LDOC, g O_2 $m^{-3}d^{-1}$

$$reLDOC2do = reLDOC * vo \tag{3.150}$$

DEPC2DO: DO consumption by mineralisation during PC death, g O_2 $m^{-3}d^{-1}$

$$dDEPC2DO = (DEPC1 + DEPC2 + DEPC3) * vm * vo \tag{3.151}$$

ODSC: Sediment DO consumption, g O_2 $m^{-3}d^{-1}$

From the sediment-water intreface oxygen (DO) can penetrat into the sediment pore water by diffusion or actively being transportet into the sediment by ventilation pumping and sediment mixing by the benthic fauna. Further microbenthic algae through photosynthetis can produce DO in the sediment-waterinterface. DO is consumed in the sediment by bacterial respiration and chemical oxidation of reduced substances (Fe^{++}, H_2S) resulting in the O_2 concentration becomes 0 (normally 0-2 cm) below the sediment surface. In the model this depth is defined as KDO2. Assuming the DO produced by the microbenthic algae is delivered to the water, the below differential equation can be set up assuming a steady state condition:

$$0 = -difo2 * \frac{d^2 O_2}{dy^2} + DOconsum \tag{3.152}$$

Where 0<y<(KDO2), which by integration becomes:

$$\frac{d\,O_2}{dy} = \frac{DOconsum}{difo2} * y + a \tag{3.153}$$

Where a is a constant, which by using the border condition ($dO_{2/dy}$=0 at y=*KDO2)*) can be defined as:

$$a = -\frac{DOconsum}{dif02} * KDO2 \Rightarrow$$

$$\frac{d\ O_2}{dy} = \frac{DOconsum}{difo2} * y - \frac{DOconsum}{difo2} * KDO2 \tag{3.154}$$

Which by yet an integration gives:

$$O_2 = \frac{DOconsum}{2 * difo2} * y^2 - \frac{DOconsum}{difo2} * KDO2 * y + b \tag{3.155}$$

Where b is a constant, which by using the border condition (O_2=0 at y=KDO2) can be defined as:

$$b = \frac{DOconsum}{2*difno3} * KDO2^{\,2} \Rightarrow$$

$$O_2 = \frac{DOconsum}{2*difo2} * y^2 - \frac{DOconsum}{difo2} * KDO2 * y + \frac{DOconsum}{difo2} * KDO2^{\,2} \tag{3.156}$$

At the sediment surface y=0 the O_2 = DO =>

$$KDO2 = \sqrt{2 * difo2 * \frac{DO}{DOconsum}} \Rightarrow$$

$$O_2 = \frac{DOconsum}{2 * difo2} * y^2 - \frac{DOconsum}{difo2} * \sqrt{2 * difo2 * \frac{DO}{DOconsum}} * y + * 2 * DO \tag{3.157}$$

The flux of DO from the water into the sediment can be described using Fick's 1. Law at depth y=0

$$DOflux = -difo2 * \frac{dO_2}{dy} \tag{3.158}$$

$\frac{dO_2}{dy}$ is found by differentiation of the above expression for O_2 in the sediment and determaine the flux of DO into the sediment at Y=0.

$$DOflux = -difo2 * \left(-\frac{DOconsum}{difo2} * \sqrt{2 * difo2 * \frac{DO}{DOconsum}}\right) \Rightarrow$$

$$DOflux = \sqrt{2 * DO * difo2 * DOconsum} \Rightarrow \tag{3.159}$$

The DO consumption in the model is the sum of bacterial respiration (*reKDO2*), nitrification (rsnit) and a flux of reduced substances from the under laying sediment (*fsh2s*) to the layer with O_2. All the mentioned DO consuming processes has the unit (g $m^{-2}d^{-1}$) and therefore has to be divided with the DO penetration (KDO2). A conversion factor for O_2:N of 4.57 g O_2 :g NH_4-N is used and a conversion factor for O_2:S of 2 g O_2 : H_2S-S is used.

The diffusion or rather transport of oxygen into the sediment is dependent of the activity of the benthic infauna. Their activity is linked to the DO concentration, at low DO (below 2 g m^{-3}) the activity will decrease caused by increased mortality. The constant *difO2* is therefore multiplied by an oxygen function (1+sqdo).

The final equation for (ODSC, g O_2 $m^{-3}d^{-1}$) in the template therefore becomes:

$$ODSC = \mathit{IF\ KDO2>0.001\ THEN}$$

$$\sqrt{2 * difO2 * (1 + sqdo) * DO * \frac{fsh2s * 2 + rsnit * 4.57 + reKDO2}{KDO2}} * \frac{1}{dz} \qquad (3.160)$$

$$\mathit{ELSE\ 0}$$

Where:

Name	Comment	Unit	Type*)
PRPC1	Production flagellate carbon	g C m^{-3} d^{-1}	P
PRPC2	Production diatom carbon	g C m^{-3} d^{-1}	P
PRPC3	Production cyanobacteria carbon	g C m^{-3} d^{-1}	P
vo	O_2:C ratio for Production & respiration	g O_2 g C^{-1}	C
hcur	Horizontal current	m s^{-1}	F
wsp	Wind speed, 10 m above sea	m s^{-1}	F
CSAIR	O_2 saturation in water, relative to PSU & temp.	g O_2 m^{-3}	A
DO	Oxygen in water	g O_2 m^{-3}	S
depth	Depth of water column	m	F
dz	Height of actual water layer	m	F
REDC	Respiration detritus	g C m^{-3} d^{-1}	P
REZC	Respiration zooplankton	g C m^{-3} d^{-1}	P
GRPC1	Grazing of phytoplankton (Flagellate) carbon	g C m^{-3} d^{-1}	P
GRPC2	Grazing of phytoplankton (diatom) carbon	g C m^{-3} d^{-1}	P
GRPC3	Grazing of cyanobacteria carbon	g C m^{-3} d^{-1}	P
refo	Zooplankton, respiration	g C g C^{-1}	C
SOXI	H_2S oxidation to SO_4	g S m^{-2} d^{-1}	P
vsh	O_2:S ratio for oxidation of H_2S to SO_4	g O_2 g S^{-1}	C
RNIT	Nitrification	g N m^{-3} d^{-1}	P

Name	Comment	Unit	Type*)
vnh	O_2:N ratio nitrification	g O_2 g N^{-1}	C
reLDOC	Respiration LDOC	g C m^{-3} d^{-1}	P
DEPC1	Death of flagellate C	g C m^{-3} d^{-1}	P
DEPC2	Death of diatom C	g C m^{-3} d^{-1}	P
DEPC3	Death of cyanobacteria C	g C m^{-3} d^{-1}	P
vm	Fraction of DEPC1-3 respired at once	n.u.	C
difO2	Diffusion of O2 in sediment	m^2 s^{-1}	C
DOconsum	Sediment O_2 consumption, layer (0-KDO2)	g O_2 $m^{-3}d^{-1}$	
y	Depth below sediment surface	m	
sqdo	DO dependend auxiliary	n.u.	A
fsh2s	H_2S flux from under laying anoxic sediment layer	g S m^{-2} d^{-1}	P
rsnit	Nitrification in sediment in oxic sediment layer	g N m^{-2} d^{-1}	P
reKDO2	Respiration in oxic sediment layer	g O m^{-2} d^{-1}	P1
KDO2	Oxic layer in sediment	m	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.23 CDOC, Coloured refractory DOC, g C m^{-3}

$$\frac{dCDOC}{dt} = depc2CDOC - phoxCDOC \tag{3.161}$$

Where:

Process	Comment	Unit
depc2CDOC	Fraction of depc to CDOC	g C m^{-3} d^{-1}
phoxCDOC	UV Photo oxidation of CDOC to LDOC	g C m^{-3} d^{-1}

depc2CDOC: Fraction of depc to CDOC, g C m^{-3} d^{-1}

$$depc2CDOC = (DEPC1 + DEPC2 + DEPC3) * vp \tag{3.162}$$

phoxCDOC: UV photo oxidation of CDOC to LDOC, g C m^{-3} d^{-1}

$$phoxCDOC = CDOC * doc_{maxde} * rd * doc_{monod} \tag{3.163}$$

Where:

Name	Comment	Unit	Type*)
DEPC1	Death of flagellate C	g C m^{-3} d^{-1}	P
DEPC2	Death of diatom C	g C m^{-3} d^{-1}	P
DEPC3	Death of cyanobacteria C	g C m^{-3} d^{-1}	P
vp	Fraction of DEPC, DEPN & DEPP to CDOC, CDON & CDOP	n.u.	C
doc_{maxde}	Max relative photo oxidation rate	d^{-1}	C
rd	Relative daylength, f(latitude, day,month,year)	n.u.	A
doc_{monod}	UV radiation Monod relation for photo oxidation	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.24 CDON, Coloured refractory DON, g N m^{-3}

$$\frac{dCDON}{dt} = depc2CDON - phoxCDON \tag{3.164}$$

Where:

Process	Comment	Unit
depc2CDON	Fraction of depn to CDON	g N m^{-3} d^{-1}
phoxCDON	UV Photo oxidation of CDON to LDON	g N m^{-3} d^{-1}

Depc2CDON: Fraction of depn to CDON, g N m^{-3} d^{-1}

$$depc2CDON = (DEPN1 + DEPN2 + DEPN3) * vp \tag{3.165}$$

phoxCDON: UV photo oxidation of CDON to LDON, g N m^{-3} d^{-1}

$$phoxCDON = CDON * doc_{maxde} * rd * doc_{monod} \tag{3.166}$$

Where:

Name	Comment	Unit	Type*)
DEPN1	Death of flagellate N	g N m^{-3} d^{-1}	P
DEPN2	Death of diatom N	g N m^{-3} d^{-1}	P
DEPN3	Death of cyanobacteria N	g N m^{-3} d^{-1}	P
vp	Fraction of depc, depn, depp to CDOC, CDON, CDOP	n.u.	C
rd	Relative daylength, f(latitude, day,month,year)	n.u.	A
doc_{maxde}	Max relative photo oxidation rate	d^{-1}	C
doc_{monod}	UV radiation Monod relation for photo oxidation	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.25 CDOP, Coloured refractory DOP, g P m^{-3}

$$\frac{dCDOP}{dt} = depc2CDOP - phoxCDOP \tag{3.167}$$

Where:

Process	Comment	Unit
depc2CDOP	Fraction of depp to CDOP	g P m^{-3} d^{-1}
phoxCDOP	UV Photo oxidation of CDOP to LDOP	g P m^{-3} d^{-1}

depc2CDOP: Fraction of depp to CDOP, g P m^{-3} d^{-1}

$$depc2CDOP = (DEPP1 + DEPP2 + DEPP3) * vp \tag{3.168}$$

phoxCDOP: UV photo oxidation of CDOP to LDOP, g P m^{-3} d^{-1}

$$phoxCDOP = CDOP * doc_{maxde} * rd * doc_{monod} \tag{3.169}$$

Where:

Name	Comment	Unit	Type*)
DEPP1	Death of flagellate P	g P m^{-3} d^{-1}	P
DEPP2	Death of diatom P	g P m^{-3} d^{-1}	P
DEPP3	Death of cyanobacteria P	g P m^{-3} d^{-1}	P
vp	Fraction of depc, depn, depp to CDOC, CDON, CDOP	n.u.	C
rd	Relative daylength, f(latitude, day,month,year)	n.u.	A
doc_{maxde}	Max relative photo oxidation rate	d^{-1}	C
doc_{monod}	UV radiation Monod relation for photo oxidation	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.26 LDOC, Labile DOC, g C m^{-3}

$$\frac{dLDOC}{dt} = phoxCDOC + depc2LDOC - reLDOC - deLDOC - sreLDOC \tag{3.170}$$

Where:

Process	Comment	Unit
phoxCDOC	UV Photo oxidation of CDOC to LDOC	g C m^{-3} d^{-1}
depc2LDOC	Fraction of depc to LDOC	g C m^{-3} d^{-1}
reLDOC	Aerobic respiration of LDOC using O_2	g C m^{-3} d^{-1}
deLDOC	Anaerobic respiration of LDOC using NO_3	g C m^{-3} d^{-1}
sreLDOC	Anaerobic respiration of LDOC using SO_4	g C m^{-3} d^{-1}

phoxCDOC: UV photo oxidation of CDOC to LDOC, g C m^{-3} d^{-1}

See under CDOC, Section 3.3.23.

depc2CDPC: Fraction of depc to LDOC, g C m^{-3} d^{-1}

$$depc2CDOC = (DEPC1 + DEPC2 + DEPC3) * vn \tag{3.171}$$

reLDOC: Aerobic respiration of LDOC using O_2, g C m^{-3} d^{-1}

$$reLDOC = LDOC * kmLC * tere^{T-20} * \frac{DO^{ndo2}}{DO^{ndo2} + mdo2} \tag{3.172}$$

deLDOC: Anaerobic respiration of LDOC using NO_3, g C m^{-3} d^{-1}

$$deLDOC = \frac{LDOC}{DC + LDOC} * (DENW * vn3 + ANAMOX * 0.429) \tag{3.173}$$

sreLDOC: Anaerobic respiration of LDOC using SO_4, g C m^{-3} d^{-1}

$$sreLDOC = \frac{LDOC}{DC + LDOC} * SRED * vso \tag{3.174}$$

Where:

Name	Comment	Unit	Type*)
DEPC1	Death of flagellate C	g C m^{-3} d^{-1}	P
DEPC2	Death of diatom C	g C m^{-3} d^{-1}	P
DEPC3	Death of cyanobacteria C	g C m^{-3} d^{-1}	P
vn	Fraction of depc, depn, depp to LDOC, LDON, LDOP	n.u.	C
tere	ϴ in Arrhenius function, DC mineralisation	n.u.	C
ndo2	DC & LDOC:Coefficient, DO mineralisation	n.u.	C
mdo2	DO half-saturation constant, DC & LDOC mineralisation	n.u	C
kmLC	Specific mineralisation rate of LDOC at 20 °C	d^{-1}	C
DC	Detritus C	g C m^{-3}	S
DENW	Denitrification in water	g N m^{-3} d^{-1}	P
vn3	C:N ratio denitrification	g C g N^{-1}	C
sred	Anoxic C mineralisation via $SO_4 \rightarrow H_2S$	g S m^{-3} d^{-1}	P
vso	C:S ratio, SO_4 respiration	g C g S^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.27 LDON, Labile DON, g N m^{-3}

$$\frac{dLDON}{dt} = phoxCDON + depc2LDON - reLDON - deLDON - sreLDON \tag{3.175}$$

Where:

Process	Comment	Unit
phoxCDON	UV Photo oxidation of CDON to LDON	g N m^{-3} d^{-1}
depc2LDON	Fraction of depn to LDON	g N m^{-3} d^{-1}
reLDON	Aerobic respiration of LDON using O_2	g N m^{-3} d^{-1}
deLDON	Anaerobic respiration of LDON using NO_3	g N m^{-3} d^{-1}
sreLDON	Anaerobic respiration of LDON using SO_4	g N m^{-3} d^{-1}

phoxCDON: UV photo oxidation of CDON to LDON, g N m^{-3} d^{-1}

See under CDON, Section 3.3.24.

depc2LDON: Fraction of depn to LDON, g N m^{-3} d^{-1}

$$depc2CDON = (DEPN1 + DEPN2 + DEPN3) * vn \tag{3.176}$$

reLDON: Aerobic respiration of LDON using O_2, g N m^{-3} d^{-1}

$$reLDON = \frac{LDON}{LDOC} * reLDOC \tag{3.177}$$

deLDON: Anaerobic respiration of LDON using NO_3, g N m^{-3} d^{-1}

$$deLDON = \frac{LDON}{LDOC} * deLDOC \tag{3.178}$$

sreLDON: Anaerobic respiration of LDON using SO_4, g N m^{-3} d^{-1}

$$sreLDON = \frac{LDON}{LDOC} * sreLDOC \tag{3.179}$$

Where:

Name	Comment	Unit	Type*)
DEPN1	Death of flagellate P	g N m^{-3} d^{-1}	P
DEPN2	Death of diatom N	g N m^{-3} d^{-1}	P
DEPN3	Death of cyanobacteria N	g N m^{-3} d^{-1}	P
vn	Fraction of depc, depn, depp to LDOC, LDON, LDOP	n.u.	C
reLDOC	Aerobic respiration of LDOC using O_2	g C m^{-3} d^{-1}	P
deLDOC	Anaerobic respiration of LDOC using NO_3	g C m^{-3} d^{-1}	P
sreLDOC	Anaerobic respiration of LDOC using SO_4	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.3.28 LDOP, Labile DOP, g P m^{-3}

$$\frac{dLDOP}{dt} = phoxCDOP + depp2LDOP - UPLDOPP3 - reLDOP - deLDOP - sreLDOP \tag{3.180}$$

Where:

Process	Comment	Unit
phoxCDOP	UV Photo oxidation of CDOP to LDOP	g P m^{-3} d^{-1}
depp2LDOP	Fraction of depp to LDOP	g P m^{-3} d^{-1}
UPLDOPP3	Cyanobacteria uptake of LDOP	g P m^{-3} d^{-1}
reLDOP	Aerobic respiration of LDOP using O_2	g P m^{-3} d^{-1}
deLDOP	Anaerobic respiration of LDOP using NO_3	g P m^{-3} d^{-1}
sreLDOP	Anaerobic respiration of LDOP using SO_4	g P m^{-3} d^{-1}

phoxCDOP: UV photo oxidation of CDOP to LDOP, g P m^{-3} d^{-1}

See under CDOP, Section 3.3.25.

depp2LDOP: Fraction of depp to LDOP, g P m^{-3} d^{-1}

$$depp2CDOP = depp * vn \tag{3.181}$$

UPLDOPP3: Cyanobacteria uptake of LDOP, g P m^{-3} d^{-1}

Please see under state variable PP3, Section 3.3.9.

reLDOP: Aerobic respiration of LDOP using O$_2$, g P m^{-3} d^{-1}

$$reLDOP = \frac{LDOP}{LDOC} * reLDOC \tag{3.182}$$

deLDOP: Anaerobic respiration of LDOP using NO$_3$, g P m^{-3} d^{-1}

$$deLDOP = \frac{LDOP}{LDOC} * deLDOC \tag{3.183}$$

sreLDOP: Anaerobic respiration of LDOP using SO$_4$, g P m^{-3} d^{-1}

$$sreLDOP = \frac{LDOP}{LDOC} * sreLDOC \tag{3.184}$$

Where:

Name	Comment	Unit	Type*)
DEPP1	Death of flagellate P	g N m^{-3} d^{-1}	P
DEPP2	Death of diatom P	g N m^{-3} d^{-1}	P
DEPP3	Death of cyanobacteria P	g N m^{-3} d^{-1}	P
Vn	Fraction of depc, depn, depp to LDOC, LDON, LDOP	n.u.	C
reLDOC	Aerobic respiration of LDOC using O$_2$	g C m^{-3} d^{-1}	P
deLDOC	Anaerobic respiration of LDOC using NO$_3$	g C m^{-3} d^{-1}	P
sreLDOC	Anaerobic respiration of LDOC using SO$_4$	g C m^{-3} d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4 Differential Equation Sediment State Variables

3.4.1 SSi, Sediment, bio-available Silicate, g Si m23

$$\frac{dSSi}{dt} = SESi - RSSi \tag{3.185}$$

Where:

Process	Comment	Unit
SESi	Deposition of Diatom & Detritus Si	g Si $m^{-2}d^{-1}$
RSSi	Flux of Si from sediment	g Si $m^{-2}d^{-1}$

SESi: Deposition of Diatom & Detritus Si, g Si $m^{-2}d^{-1}$

$$SESi = (SEPSi2 + SEDSi) * dz \tag{3.186}$$

RSSi: Flux of Si from sediment, g Si $m^{-2}d^{-1}$

$$RSSi = krss * trss^{T-20} * \frac{SSi}{SSi + hss1} * MAX(1, MIN\left(2, \frac{0.005}{KDOX}\right)) \tag{3.187}$$

Where:

Name	Comment	Unit	Type*)
SEPSi2	Sedimentation of diatom Si	g Si $m^{-3}d^{-1}$	P
SEDSi	Sedimentation of detritus Si	g Si $m^{-3}d^{-1}$	P
dz	Height of actual water layer	M	F
krss	Max Si release rate from sediment at 20 °C	g Si $m^{-2}d^{-1}$	C
trss	Ɵ value in Arrhenius temperature function, Si	n.u.	C
T	Temperature	°C	F
hss1	Half saturation constant for SSi	g Si m^{-2}	C
KDOX	NO_3 penetration depth in sediment	M	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.2 KDOX, depth of NO3 penetration in sediment, m

KDOX is the NO_3 penetration into the sediment. NO_3 is denitrified in the anoxic part of the sediment and therefore normally only penetrate 0-10 cm into the sediment. Normally, DO only penetrates a few mm into the sediment and therefore KDO2 (the DO penetration) will be smaller than KDOX. In a simulation, a situation may occur where KDOX is smaller than KDO2, which at least in theory may happen in nature. In this case, the increase in KDOX is set to a fixed fraction of the difference between KDO2 and KDOX.

$$\frac{dKDOX}{dt} = dkdox \tag{3.188}$$

Where:

Process	Comment	Unit
Dkdox	change oxidised layer sediment, KDOX	m d^{-1}

Change oxidised layer sediment, KDOX:

$$\begin{aligned} &dkdox = \text{IF KDOX<KDO2} \\ &\text{THEN} \\ &(KDOX - KDO2) * kkdox \\ &\text{ELSE} \\ &\text{dkdox\_no3} \end{aligned} \tag{3.189}$$

Where:

Name	Comment	Unit	Type*)
KDO2	DO penetration into sediment	m	S
kkdox	NO_3 penetration rate constant into sediment, KDOX<KDO2	d^{-1}	C
dkdox_no3	NO_3 penetration rate sediment, analytical solution	m d^{-1}	P1

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.3 KDO2, DO penetration in sediment, m

$$\frac{dKDO2}{dt} = dkdo2 \tag{3.190}$$

Where:

Process	Comment	Unit
dkdo2	change in DO penetration in sediment	m d^{-1}

dkdo2: Change in DO penetration in sediment, m d^{-1}

```
$dkdo2$ =IF (kds-KDO2)<epsi
THEN
$MIN(kdo2i - KDO2) * kkdo2,0)$
ELSE
(kdo2i-KDO2)*kkdo2
```

(3.191)

Where:

Name	Comment	Unit	Type*)
KDO2	DO penetration into sediment	m	S
kds	Depth of modelled sediment layer	m	C
epsi	Constant small value also used for PC nutrient uptake	n.u.	C
kdo2i	New steady state condition for KDO2, function of DO and respiration, analytical solution	m	P1
kkdo2	Rate constant for DO penetration into sediment	C	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.4 SOC, Sediment organic C, g C m^{-2}

$$\frac{dSOC}{dt} = depoC - minSOC - rscim \tag{3.192}$$

Where:

Process	Comment	Unit
depoC	Deposition of C	g C $m^{-2}d^{-1}$
minSOC	Mineralisation of SOC	g C $m^{-2}d^{-1}$
Rscim	Burial of sediment organic C	g C $m^{-2}d^{-1}$

Deposition of C on sediment surface:

$$depoC = (\mathrm{SEPC1\text{-}BUOYC1+SEP2+SEPC3\text{-}BUOYC3+SEDC})*\underline{\mathrm{dz}} \tag{3.193}$$

Where:

Name	Comment	Unit	Type*)
SEPC1	Sedimentation of flagellate C	g C m^{-3} d^{-1}	P
SEPC2	Sedimentation of diatom C	g C m^{-3} d^{-1}	P
SEPC3	Sedimentation of cyanobacteria C	g C m^{-3} d^{-1}	P
BUOYC1	Flagellate upward movement	g C m^{-3} d^{-1}	P
BUOYC3	Cyanobacteria upward movement	g C m^{-3} d^{-1}	P
SEDC	Sedimentation of detritus C (DC) to sediment	g C m^{-3} d^{-1}	P
Dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

minSOC: Mineralisation of SOC, g C $m^{-2}d^{-1}$

$$minSOC = \mathrm{krsc1*SOC*}tetn^{T-20} + \mathrm{fscb*dz} \tag{3.194}$$

Where:

Name	Comment	Unit	Type*)
krsc1	Specific mineralisation rate of SOC 20 °C	d^{-1}	C
tetn	ϴ in Arrhenius temperature equation, SON mineralisation	n.u.	C
temp	Temperature	°C	F
fscb	Mineralisation of newly settled organic C	g C $m^{-3}d^{-1}$	P1
Dz	Height of actual layer= layer above sediment	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

rscim: Burial of sediment organic C, g C $m^{-2}d^{-1}$

$$rscim = (depoC - fscb * dz) * \frac{rsnim}{rson} \tag{3.195}$$

Where:

Name	Comment	Unit	Type*)
depoC	Deposition of C	g C $m^{-2}d^{-1}$	P
Fscb	Mineralisation of newly settled organic C	g C $m^{-3}d^{-1}$	P1
Rsnim	Burial of organic sediment N (SON), see SON (Section 3.4.5)	g N $m^{-2}d^{-1}$	P
Rson	Burial of organic sediment N (SON), see SON (Section 3.4.5)	g N $m^{-2}d^{-1}$	P
Dz	Height of actual layer= layer above sediment	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.5 SON, Bio-available organic N in sediment, g N m^{-2}

$$\frac{dSON}{dt} = rson - rsonnh - rsnim \tag{3.196}$$

Where:

Process	Comment	Unit
Rson	Settling of organic N to SON	g N m^{-2}d^{-1}
Rsonnh	Mineralisation of SON to pore water NH_4	g N m^{-2}d^{-1}
Rsnim	Burial of organic sediment N (SON)	g N m^{-2}d^{-1}

rson: Settling of organic N to SON

$$rson = (SEPN1 - \mathbf{BUOYN1} + SEPN2 + SEPN3 - \mathbf{BUOYN3} + SEDN - fsnb) * dz \tag{3.197}$$

Where:

Name	Comment	Unit	Type*)
SEPN1	Sedimentation of flagellate N	g N m^{-3} d^{-1}	P
SEPN2	Sedimentation of diatom N	g N m^{-3} d^{-1}	P
SEPN3	Sedimentation of cyanobacteria N	g N m^{-3} d^{-1}	P
BUOYN1	Flagellate upward movement N	g N m^{-3} d^{-1}	P
BUOYN3	Cyanobacteria upward movement N	g N m^{-3} d^{-1}	P
SEDN	Sedimentation of detritus N, (DN), see DN	g N m^{-3} d^{-1}	P
Fsnb	Mineralisation of newly settled organic N on sed. surface	g N m^{-3} d^{-1}	P1
Dz	Height of actual layer= layer above sediment	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

rsonnh: Mineralisation of SON to pore water NH_4

$$rsonh = krsn1 * SON * tetn^{T-20} \tag{3.198}$$

Where:

Name	Comment	Unit	Type*)
krsn1	Specific mineralisation rate of SON 20 °C	d^{-1}	C
Tetn	ϴ in Arrhenius temperature equation, SON mineralisation	n.u.	C
T	Temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

rsnim: Burial of organic sediment N (SON), g N $m^{-2}d^{-1}$

The mineralisation of SOC and SON is assumed to a function of the sediment SON:SOC ratio. At low SON:SOC ratios close to *knim* the mineralisation is assumed to small or close to 0. The fraction of organic N settled to the sediment (*rson*) to buried or immobilised is set to be *knim* multiplied with settled organic C to sediment. If N:C ration of the settled N is below *knim* all settled N (rson) is buried.

$$\begin{array}{l} rsnim = IF\ knim * (depoC - fscb * dz) < rson \\ THEN \\ knim * (depoC - fscb * dz) \\ \mathrm{ELSE} \\ \mathrm{Rson} \end{array} \tag{3.199}$$

Where:

Name	Comment	Unit	Type*)
knim	Sediment: N:C ratio of immobile N	g N g C^{-1}	C
depoC	Deposition of C, see SOC	g C $m^{-2}d^{-1}$	P
fscb	Mineralisation of newly settled organic C	g C $m^{-3}d^{-1}$	P1
rson	Settling of organic N to SON	g N $m^{-2}d^{-1}$	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.6 SOP, Bio-available organic P in sediment, g P m^{-2}

$$\frac{dSOP}{dt} = rsop - ropsip - rspim \tag{3.200}$$

Where:

Process	Comment	Unit
rsop	Settling of organic P to SOP	g P $m^{-2}d^{-1}$
ropsip	Mineralisation of SOP to pore water PO_4	g P $m^{-2}d^{-1}$
rspim	Burial – immobilisation of organic sediment P (SOP)	g P $m^{-2}d^{-1}$

rsop: Settling of organic P to SOP, g P $m^{-2}d^{-1}$

$$rsop = (SEPP1 - \boldsymbol{BUOYP1} + SEPP2 + SEPP3 - \boldsymbol{BUOYP3} + SEDP - fspb) * dz \tag{3.201}$$

Where:

Name	Comment	Unit	Type*)
SEPP1	Sedimentation of flagellate P	g P m^{-3} d^{-1}	P
SEPP2	Sedimentation of diatom P	g P m^{-3} d^{-1}	P
SEPP3	Sedimentation of cyanobacteria P	g P m^{-3} d^{-1}	P
BUOYP1	Flagellate upward movement P	g P m^{-3} d^{-1}	P
BUOYP3	Cyanobacteria upward movement P	g P m^{-3} d^{-1}	P
Fspb	Mineralisation of newly settled organic P on sed. Surface	g P m^{-3} d^{-1}	P1
Dz	Height of actual layer= layer abowe sediment	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

ropsip: Mineralisation of SOP to pore water PO_4, g P $m^{-2}d^{-1}$

$$ropsip = krsp1 * SOP * tetp^{T-20} \tag{3.202}$$

Where:

Name	Comment	Unit	Type*)
krsp1	Specific mineralisation rate of SOP 20 °C	d^{-1}	C
tetp	ϴ in Arrhenius temperature equation, SOP mineralisation	n.u.	C
T	Temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

rspim: Burial and immobilisation of organic sediment P (SOP), g P $m^{-2}d^{-1}$

P is able to be incorporated into hydroxyapatite (chalk) or adsorbed to reduced Fe (in fresh waters) or simply it is incorporated into inert organic C. The processes are not well known and therefore a fixed fraction of the settled organic P is immobilised. In sediments (typical marine) where the pool of H2S (reduced substances) exceeds a fixed value of 0.01 g S m-2 immobilisation to Fe++ is reduced to 1/10.

The user may change the process if new information is available, or information on sediment type prescribes another formulation.

$$rspim = IF\ H2S > 0.01\ THEN\ \frac{kpim}{10} * rsop\ ELSE\ kpim * rsop \tag{3.203}$$

Where:

Name	Comment	Unit	Type*)
knim	Sediment: P:C ratio of immobile P	g P g C^{-1}	C
rsop	Settling of organic P to SOP	g N $m^{-2}d^{-1}$	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.7 FESP, PO4 adsorbed to oxidised ion in sediment, g P m^{-2}

$$\frac{dFESP}{dt} = rfesip \tag{3.204}$$

Where:

Process	Comment	Unit
rfesip	Flux between pore water PO_4 and iron-absorped P	g P $m^{-2}d^{-1}$

rfesip: Flux between pore water PO_4 and iron-absorped P, g P $m^{-2}d^{-1}$

The exchange of PO_4-P between oxidised ion (Fe^{+++}) is calculated as a rate constant (*krap*) multiplied with the difference between a new steady state sorption of PO_4 to Fe+++ (*FESP_f(KDOX)*$_\infty$) and the last calculated pool of sorbed PO_4-P (*FESP*$_t$).

An approximation of *FESP_f(KDOX)*$_\infty$ is estimated using a Monod kinetic for PO_4 in the pore water combined with information of sediment ion conten, dry matter sediment, density and finaly multiplied with the oxidised layer (KDOX), which is a state variable in the model.

$$rfesip = krap * (FESP\_f(KDOX)_\infty - FESP_t) \quad =>$$

$$rfesip = krap * (kfe * kfepo * \frac{SIPm3}{SIPm3 + khfe} * vf * dm * KDOX * 10^6 - FESP) \tag{3.205}$$

Where:

Name	Comment	Unit	Type*)
krap	Rate constant for iron absorption – desorption of PO_4	d^{-1}	C
kfe	Oxidable ion content in sediment	g Fe g dw^{-1}	C
Kfepo	Maximum Fe-P sorption capacity	g P g Fe^{-1}	C
SIPm3	Pore water PO_4 concentration	g P m^{-3}	A
khfe	Half saturation constant, adsorption-desorption	g P m^{-3}	C
vf	Sediment density	g WW cm^{-3}	C
dm	Dry weight sediment	g DM g WW^{-1}	C
KDOX	Depth of No3 penetration ~oxidised layer with Fe^{+++}	m	S
FESP	Ion(FE^{+++}) bound PO4 in sediment	g P m^{-2}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.8 SNH, Sediment pore water NH4, g N m^{-2}

$$\frac{dSNH}{dt} = rsonnh - rsnit - feunh4 \tag{3.206}$$

Where:

Process	Comment	Unit
rsonnh	Mineralisation of SON to pore water NH_4	g N m^{-2}d^{-1}
rsnit	Nitrification of NH_4 in sediment	g N m^{-2}d^{-1}
feunh4	NH_4 Flux between sediment pore water and water	g N m^{-2}d^{-1}

rsonnh: mineralisation of SON to pore water NH_4, g N m^{-2}d^{-1}

Please see under the state variable SON, Section 3.4.5.

rsnit: Nitrification of NH_4 in sediment, g N m^{-2}d^{-1}

The nitrification of NH4 in sediment pore water (*SNHm3*) is described as the product between a specific nitrification rate (knit), SNHm3, a Monod relation of *SNHm3* a Monod relation for DO (*sqdo*), the DO penetration in the sediment (*KDO2*) and a temperature relation.

$$\begin{array}{l} rsnit = \text{IF DO>0} \\ \text{THEN} \\ knit * SNHm3 * \dfrac{SNHm3}{SNHm3 + ksnh0} * sqdo * KDO2 * tetn^{T-20} \\ \text{ELSE} \\ 0 \end{array} \tag{3.207}$$

Where:

Name	Comment	Unit	Type*)
Knit	Specific nitrification rate at 20 C in sediment	d^{-1}	C
SNHm3	NH_4 concentration in pore water	g N m^{-3}	A
ksnh0	NH_4 half saturation concentration for nitrification	g N m^{-3}	C
Sqdo	DO Mond function	n.u.	A
KDO2	DO penetration in sediment	m	S
Tetn	Ɵ in Arrhenius temperature equation, SON mineralisation	n.u.	C
T	Temperature	°C	F

*)	S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

feunh4: NH_4 Flux between sediment pore water and water, g N $m^{-2}d^{-1}$

The flux between pore water NH_4 (*SNHm3*) and NH_4 in the water (*NH4*) is described as a product of a vertical diffusion constant (*difnh*) and concentration difference divided with the the NO_3 penetration depth in the sediment (*KDOX*).

$$feunh4 = difnh * \frac{SNHm3 - NH4}{MIN(kds, KDOX)} \tag{3.208}$$

Where:

Name	Comment	Unit	Type*)
difnh	Vertical diffusion for ammonia	m^2d^{-1}	C
SNHm3	NH_4 concentration in pore water	g N m^{-3}	A
NH4	NH_4 concentration in water	g N m^{-3}	C
kds	Depth of modelled sediment layer	m	C
KDOX	NO_3 penetration in sediment~oxidised layer	m	S

*)	S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.9 SNO3, NO3 in sediment pore water, layer (0 - kdo2), g N m^{-2}

$$\frac{dSNO3}{dt} = rsnit - rdenit - feuno3 \tag{3.209}$$

Where:

Process	Comment	Unit
rsnit	Nitrification of pore water NH_4 in sediment	g N $m^{-2}d^{-1}$
Rdenit	Denitrification of NO_3 in sediment	g N $m^{-2}d^{-1}$
feuno3	NO_3 Flux between sediment pore water and water	g N $m^{-2}d^{-1}$

rsnit: Nitrification of pore water NH_4 in sediment, g N $m^{-2}d^{-1}$

Please see state variable SNH, Section 3.4.8.

rdenit: Denitrification of NO_3 in sediment, g N $m^{-2}d^{-1}$

rdenit is expressed as flux of NO_3 into the anoxic zone of the sediment where only diffusion and denitrification are the driving processes. An analytical solution is used assuming steady state conditions.

From the surface layer of the sediment with DO (*KDO2*), NO_3 in the pore water with concentration *SNO3m3* will penetrate deeper into the anoxic sediment layer while being denitrified to N_2. At a sudden depth below the surface (*KDOX*) NO_3 concentration will be 0. Assuming a constant denitrification and under steady state condition the NO_3 concentration (*NO3x)* in the pore water at depth x below the surface layer with DO can be described with:

$$0 = -difno3 * \frac{d^2NO3x}{dx^2} + dnm3 \text{ Where } 0<x<(KDOX-KDO2) \tag{3.210}$$

Which by integration becomes:

$$\frac{d\ NO3x}{dx} = \frac{dnm3}{difno3} * x + a \tag{3.211}$$

Where a is a constant, which by using the border condition (*dNO3x/dx*=0 at x=(*KDOX-KDO2)*) can be defined as:

$$a = -\frac{dnm3}{difno3} * (KDOX - KDO2) \Rightarrow$$

$$\frac{d\ NO3x}{dx} = \frac{dnm3}{difno3} * (x - (KDOX - KDO2)) \tag{3.212}$$

Which by yet an integration gives:

$$NO3x = \frac{dnm3}{2 * difno3} * x^2 * -\frac{dnm3}{difno3} * (KDOX - KDO2) * x + b \tag{3.213}$$

Where b is a constant, which by using the border condition (*SNO3m3*=0 at x=(*KDOX-KDO2)*) can be defined as:

$$b = \frac{dnm3}{2*difno3} * (KDOX - KDO2)^2 \Rightarrow$$

$$NO3x = \frac{dnm3}{2*difno3} * x^2 - \frac{dnm3}{difno3} * (KDOX - KDO2) * x + \frac{dnm3}{2*difno3} * (KDOX - KDO2)^2 \tag{3.214}$$

At depth x=0 in the anoxic zone (which is at depth KDO2 below sediment surface) *NO3x=SNO3m3*. =>

$$(KDOX - KDO2) = \sqrt{2 * difno3 * \frac{SNO3m3}{dnm3}} \Rightarrow$$

$$NO3x = \frac{dnm3}{2 * difno3} * x^2 - \frac{dnm3}{difno3} * \sqrt{2 * difno3 * \frac{SNO3m3}{dnm3}} * x + 2 * SNO3m3 \tag{3.215}$$

Assuming the flux of NO_3 into the anoxic sediment solely being created by denitrification the NO_3-flux=denitrification pr. m^2 d^{-1} = rdenit.

Using Fick's 1. law for a flux at depth x=0.

$$rdenit = -difno3 * \frac{dNO3x}{dx} \tag{3.216}$$

$\frac{dNO3x}{dx}$ is found by differentiation of the above expression for *NO3x* and determine the flux for x=0. The final equation used in the template:

$$rdenit = \sqrt{2 * difno3 * dnm3 * SNO3m3} \tag{3.217}$$

Where:

Name	Comment	Unit	Type*)
difno3	Vertical diffusion for NO_3 in sediment	m^2d^{-1}	C
dnm3	denitrification in sediment, corrected for temperature	$g\ N\ m^{-3}d^{-1}$	A
SNO3m3	NO_3 in pore water surface sediment, layer (0-kdo2)	$g\ N\ m^{-3}$	A
KDO2	DO penetration into the sediment	m	S
KDOX	NO_3 penetration into the sediment	m	S
NO3x	NO_3 concentration in pore water at depth x	$g\ N\ m^{-3}$	
X	Depth below zone with DO	m	

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

feuno3: NO_3 Flux between sediment pore water and water, g N $m^{-2}d^{-1}$

The flux between pore water NO_3 (*SNO3m3*) and NO_3 in the water (*NO3*) is described as a product of a vertical diffusion constant (*difno3*) and concentration difference divided with the the DO penetration depth in the sediment (*KDO2*).

$$feuno3 = difno3 * \frac{SNO3m3 - NO3}{KDO2} \tag{3.218}$$

Where:

Name	Comment	Unit	Type*)
difno3	Vertical diffusion for NO_3 in sediment	m^2d^{-1}	C
NO3	NO_3 concentration in water	$g\ N\ m^{-3}$	S
SNO3m3	NO_3 in pore water surface sediment, layer (0-kdo2)	$g\ N\ m^{-3}$	A
KDO2	DO penetration into the sediment	m	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.10 SIP, PO4 in sediment pore water, g P m^{-2}

$$\frac{dSIP}{dt} = -rfesip + ropsip - fsip \tag{3.219}$$

Where:

Process	Comment	Unit
rfesip	Flux between pore water PO_4 and iron-adsorbed P	g P $m^{-2}d^{-1}$
ropsip	Mineralisation of SOP to pore water PO_4	g P $m^{-2}d^{-1}$
fsip	Flux between PO_4 in pore water and water above sediment	g P $m^{-2}d^{-1}$

rfesip: Flux between pore water PO_4 and iron-absorped P, g P $m^{-2}d^{-1}$

Please see under the stat variable FESP, sediment ion adsorbed PO_4, Section 3.4.7.

ropsip: Mineralisation of SOP to pore water PO_4, g P $m^{-2}d^{-1}$

Please see under the stat variable SOP, bio-available organic P in sediment. Section 3.4.6.

fsip: Flux between PO_4 in pore water and water above sediment, g P $m^{-2}d^{-1}$

The flux between pore water PO_4 (*SIPm3*) and PO_4 in the water (IP) is described as a product of a vertical diffusion constant (*kfip*) and concentration difference divided with the NO_3 penetration depth in the sediment (*KDOX*).

$$fsip = kfip * \frac{SIPm3 - IP}{KDOX} \tag{3.220}$$

Where:

Name	Comment	Unit	Type*)
kfip	Vertical diffusion for PO_3 in sediment	m^2d^{-1}	C
IP	PO_4 concentration in water	g N m^{-3}	S
SIPm3	PO_4 in pore water of the sediment	g N m^{-3}	A
KDOX	NO_3 penetration into the sediment	m	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.11 SH2S, Reduced substances in sediment, g S m^{-2}

$$\frac{dH2S}{dt} = RSH2S - fsh2s - fwsh2s \tag{3.221}$$

Where:

Process	Comment	Unit
RSH2S	Sediment H2S production in anaroxic layer: mineralisation of SOC – denitrification	g S m^{-2}d^{-1}
fsh2s	flux of SH2S from reduced sediment (below KDOX) to oxidised sediment.	g S m^{-2}d^{-1}
fwsh2	flux of reduced H2S equivalents from sediment to water	g S m^{-2}d^{-1}

RSH2S: Sediment H2S production in anaroxic layer: mineralisation of SOC minus denitrification

The production of H2S (reduced substances in sediment expressed as H_2S-S) is calculated as the mineralisation of SOC (minSOC) minus the a fraction of the minSOC being oxidised by DO in layer KDO2 minis a fraction of minSOC being oxidised by NO_3 by denitrification in the anoxic zone penetrated by NO_3 (KDOX-KDO2). A C:N ratio of 1.07 is used to convert denitrified NO_3-N to C, and a C:S ratio of 1.33 is used to convert mineralised C to S.

$$RSH2S = \left(minSOC - \frac{erKDO2}{vo} - rdenit * 1.07\right) * 1.33 \tag{3.222}$$

Where:

Name	Comment	Unit	Type*)
minSOC	mineralisation SOC	g C m^{-2}d^{-1}	P
reKDO2	Sediment mineralisation of SOC by DO, in layer KDO2	g O_2 m^{-2}d^{-1}	P1
Vo	O_2: C ratio used in production & consumption processes	g O_2 g C^{-1}	C
Rdenit	Denitrification in anoxic sediment layer	g N m^{-2}d^{-1}	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

fsh2s: flux of SH2S from reduced sediment (below KDOX) to oxidised sediment, g S $m^{-2}d^{-1}$

The flux of reduced substances expressed as H_2S-S from sediment below the oxidised zone of the sediment (below KDOX) is expressed as a diffusion constant multiplied by a H_2S concentration difference between the H_2S concentration (calculated from SH2S) and the H2S concentration in the water above the sediment divided by the distance from the reduced zone in the sediment to the depth of DO penetration (KDO2).

$$\begin{aligned} &fsh2s = IF\ KDO2 > 0.001 \\ &THEN \\ &difh2s * \frac{\dfrac{SH2S}{(1-dm)*vf*\left(kds - MAX\left(KDO2, (KDOX - KDO2)\right)\right)} - H2S}{KDOX - KDO2} \\ &ELSE\ 0 \end{aligned} \tag{3.223}$$

Where:

Name	Comment	Unit	Type*)
difh2s	Vertical diffusion of SH2S in sediment	m^2d^{-1}	C
SH2S	Reduced substances in sediment as H_2S	g S m^{-2}	S
vf	Sediment density	g WW cm^{-3}	C
dm	Dry weight sediment	g DM g WW^{-1}	C
kds	Depth of modelled sediment layer	m	C
KDO2	DO penetration into the sediment	m	S
KDOX	NO_3 penetration into the sediment	m	S
H2S	Hydrogen sulphide in water above sediment (H_2S)	g S m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

fwsh2s: flux of reduced H2S equivalents from sediment to water, g S m^{-2} d^{-1}
In case the DO penetration in the sediment (KDO2) is below 1 mm the flux of H_2S go directly from the reduced zone of the sediment into the water above the sediment.

$$\begin{aligned}&fwsh2s = IF\ KDO2 \leq 0.001\\&THEN\\&\qquad dif h2s * \frac{\frac{SH2S}{(1-dm)*vf*(kds-KDO2)} - H2S}{KDOX}\\&ELSE\ 0\end{aligned} \qquad (3.224)$$

Where:

Name	Comment	Unit	Type*)
difh2s	Vertical diffusion of SH2S in sediment	m^2d^{-1}	C
SH2S	Reduced substances in sediment as H_2S	g S m^{-2}	S
Vf	Sediment density	g WW cm^{-3}	C
Dm	Dry weight sediment	g DM g WW^{-1}	C
Kds	Depth of modelled sediment layer	m	C
KDO2	DO penetration into the sediment	m	S
KDOX	NO_3 penetration into the sediment	m	S
H2S	Hydrogen sulphide in water above sediment (H_2S)	g S m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.12 SPIM, Immobilised sediment P, g P m^{-2}

$$\frac{dSPIM}{dt} = rspim \qquad (3.225)$$

Where:

Process	Comment	Unit
Rspim	Immobilisation of sediment P	g P $m^{-2}d^{-1}$

rspim: Immobilisation of sediment P, g P m^{-2}d^{-1}

The immobilisation of P in the sediment is set to be a constant fraction of the organic P settling to the sediment surface. In water bodies with permanently or semi permanent anoxia having a H_2S concentration above 0.01 g S m^{-3} the immobilisation is set to be 10% of

$$rspim = IF\ H2S > 0.01\ THEN$$

$$\frac{kpim}{10} * rsop \tag{3.226}$$

$$ELSE\ \ kpim * rsop$$

Where:

Name	Comment	Unit	Type*)
H2S	H_2S in the water above the sediment	g S m^{-3}	S
kpim	Fraction of settled P to immobilisation	n.u.	C
rsop	Supply of organic P to sediment	g P $m^{-2}d^{-1}$	P

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.4.13 SNIM, Immobilised sediment N by denitrification & burial, g N m^{-2}

$$\frac{dSNIM}{dt} = rsnim + rdenit \tag{3.227}$$

Where:

Process	Comment	Unit
rspim	Immobilisation of sediment N by burial	g N $m^{-2}d^{-1}$
rdenit	Denitrification of NO_3 in sediment	g N $m^{-2}d^{-1}$

rsnim: Immobilisation of sediment N by burial, g N $m^{-2}d^{-1}$

Please see under state variable sediment organic N (SON), Section 3.4.5.

rdenit: Denitrification of NO_3 in sediment, g N $m^{-2}d^{-1}$

Please see under state variable sediment NO3 (SN03), Section3.4.9.

3.4.14 SNIM, Immobilised sediment N by denitrification & burial, g N m^{-2}

$$\frac{dSCIM}{dt} = minSOC + rscim \tag{3.228}$$

Where:

Process	Comment	Unit
minSOC	Mineralisation of SOC	g C m^{-2}d^{-1}
rscim	Burial of sediment organic C	g C m^{-2}d^{-1}

minSOC: Mineralisation of SOC, g C m^{-2}d^{-1}

Please see under state variable sediment organic C (SOC), Section 3.4.4.

rscim: Burial of sediment organic C, g C m^{-2}d^{-1}

Please see under state variable sediment organic C (SOC), Section 3.4.4.

3.5 Help Processes

The help processes are divided into processes not included into differential equations (P1) and auxiliary processes (A). The distinction between is unimportant and relay on P1 processes in MIKE ECO Lab being able to be defined exclusively for bottom layer, surface layer and all layers in a 3D model. This distinction is not possible for auxiliary processes.

3.5.1 The P1 processes listed in alphabetic order

dkdox_no3: Change in NO3 penetration rate sediment, analytical solution, m d^{-1}

NO_3 in the pore water of the sediment is caused by penetration of NO_3 form water above the sediment and by nitrification of NH_4 in the uppermost layer (KDO2) with DO in the pore water. The NO_3 concentration in this layer (0 to KDO2) has in the model the average concentration S*NO3m3.* From this layer NO_3 penetrates deeper into the anoxic sediment layer while being denitrified to N_2. Provided there is no outflow of NO_3 enriched ground water the NO_3 concentration at a sudden depth below the surface (*KDOX*) will be 0. Assuming a constant denitrification and under steady state condition the NO_3 concentration (*NO3x)* in the pore water at depth x below the surface layer with DO can be described with:

$$0 = -difno3 * \frac{d^2NO3x}{dx^2} + dnm3 \text{ Where } 0<x<(KDOX_\infty\text{-}KDO2) \tag{3.229}$$

Which by integration becomes:

$$\frac{d\ NO3x}{dx} = \frac{dnm3}{difno3} * x + a \tag{3.230}$$

Where a is a constant, which by using the border condition (*dNO3x/dx*=0 at x=(*KDOX-KDO2)*) can be defined as:

$$a = -\frac{dnm3}{difno3} * (KDOX_\infty - KDO2) \Rightarrow$$

$$\frac{d\ NO3x}{dx} = \frac{dnm3}{difno3} * (x - (KDOX_\infty - KDO2)) \tag{3.231}$$

Which by yet an integration gives:

$$NO3x = \frac{dnm3}{2*difno3} * x^2 - \frac{dnm3}{difno3} * (KDOX_\infty - KDO2) * x + b \tag{3.232}$$

Where b is a constant, which by using the border condition (*SNO3m3*=0 at x=(*KDOX*$_\infty$-*KDO2)*) can be defined as:

$$b = \frac{dnm3}{2*difno3} * (KDOX_\infty - KDO2)^2 \Rightarrow$$

$$NO3x = \frac{dnm3}{2*difno3} * x^2 - \frac{dnm3}{difno3} * (KDOX_\infty - KDO2) * x + \frac{dnm3}{2*difno3} * (KDOX_\infty - KDO2)^2 \tag{3.233}$$

At depth x=0 in the anoxic zone (which is at depth KDO2 below sediment surface) *NO3x=SNO3m3*. =>

$$(KDOX_{\infty} - KDO2) = \sqrt{2 * difno3 * \frac{SNO3m3}{dnm3}} \Rightarrow$$

$$KDOX_{\infty} = \sqrt{2 * difno3 * \frac{SNO3m3}{dnm3}} + KDO2 \tag{3.234}$$

$KDOX_{\infty}$ in the above equation is the NO_3 peneteration in the sediment under steady state condition. Assuming $KDO2_t$ ~$KDO2_{t+1}$ the change in the change in in KDOX (kdox_no3) from time step t to time step t+1 can the be defined as:

$$dkdox_{no3} = (KDOX_{\infty} - KDOX_t) * kkdox$$

$$dkdox_{no3} = \left(\sqrt{2 * difno3 * \frac{SNO3m3}{dnm3}} + KDO2_t - KDOX_t\right) * kkdox \tag{3.235}$$

Where:

Name	**Comment**	**Unit**	**Type*)**
difno3	Vertical diffusion for NO_3 in sediment	m^2d^{-1}	C
dnm3	denitrification in sediment, corrected for temperature	g N $m^{-3}d^{-1}$	A
SNO3m3	NO_3 in pore water surface sediment, layer (0-kdo2)	g N m^{-3}	A
KDO2	DO penetration into the sediment	m	S
$KDO2_t$	DO penetration into the sediment , time step t	m	
KDOX	NO_3 penetration into the sediment, same as $KDOX_t$	m	S
kkdox	Rate constant NO_3 penetration into sediment	d^{-1}	C
$KDOX_t$	NO_3 penetration into the sediment, time step t	m	
$KDOX_{\infty}$	NO_3 penetration into the sediment, steady state	m	
NO3x	NO_3 concentration in pore water at depth x	g N m^{-3}	
x	Depth below zone with DO	m	

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

fscb: Mineralisation of newly settled organic C, g C m^{-3}d^{-1}

A fraction of newly settled particulate organic C (plankton and detritus) on the sediment surface is assumed to be mineralised at once. The fraction mineralised is dependent on the N:C ratio.

$$fscb = \frac{fsnb}{SEPN1 - BUOYN1 + SEPN2 + SEPN3 - BUOYN3 + SEDN} * \frac{depoC}{dz} \tag{3.236}$$

Where:

Name	Comment	Unit	Type*)
fsnb	Mineralisation of newly settled organic N	g N m^{-3}d^{-1}	P1
depoC	Deposition of particulate organic C	g C m^{-2}d^{-1}	P
SEPN1	Sedimentation of flagellate N	g N m^{-3} d^{-1}	P
SEPN2	Sedimentation of diatom N	g N m^{-3} d^{-1}	P
SEPN3	Sedimentation of cyanobacteria N	g N m^{-3} d^{-1}	P
BUOYN1	Flagellate upward movement N	g N m^{-3} d^{-1}	P
BUOYN3	Cyanobacteria upward movement N	g N m^{-3} d^{-1}	P
SEDN	Deposition of detritus N	g N m^{-3}d^{-1}	P
dz	Height of actual layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

fsnb: Mineralisation of newly settled organic N, g N m^{-3}d^{-1}

A fraction of newly settled particulate organic N (plankton, detritus and dead eelgrass) on the sediment surface is assumed to be mineralised at once. The fraction mineralised is dependent on the N:C ratio.

$$fsnb = krsn0 * \left(SEPN1 - BUOYN1 + SEPN2 + SEPN3 - BUOYN3 + SEDN - \frac{depoC * knim}{dz}\right) * tetn^{temp-20} \tag{3.237}$$

Where:

Name	Comment	Unit	Type*)
krsn0	Fraction of deposited N mineralised	d^{-1}	C
depoC	Deposition of particulate organic C	g C m^{-2}d^{-1}	P
SEPN1	Sedimentation of flagellate N	g N m^{-3} d^{-1}	P

Name	Comment	Unit	Type*)
SEPN2	Sedimentation of diatom N	g N m^{-3} d^{-1}	P
SEPN3	Sedimentation of cyanobacteria N	g N m^{-3} d^{-1}	P
BUOYN1	Flagellate upward movement N	g N m^{-3} d^{-1}	P
BUOYN3	Cyanobacteria upward movement N	g N m^{-3} d^{-1}	P
SEDN	Deposition of detritus N	g N $m^{-3}d^{-1}$	P
dz	Height of actual layer	m	F
knim	Sediment N:C ratio of immobile N	g N g C^{-1}	C
tetn	Θ value in Arrhenius temperature function	n.u.	C
temp	Temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

fspb: Mineralisation of newly settled organic P, g P $m^{-3}d^{-1}$

A fraction of newly settled particulate organic P (plankton and detritus) on the sediment surface is assumed to be mineralised at once. The fraction mineralised is not set to be dependent on the N:C ratio, because mineralised P as PO_4 can be adsorbed to resuspended fine sediment containing Fe^{+++}. The user should therefore consider this problem and set the constant *krsp0* accordingly, from model set up to model set up.

$$fspb = krsp0 * (SEPP1 - SUOYP1 + SEPP2 + SEPP3 - BUOYP3 + SEDP) * tetp^{temp-20} \tag{3.238}$$

Where:

Name	Comment	Unit	Type*)
krsp0	Fraction of deposited N mineralised	d^{-1}	C
SEPP1	Sedimentation of flagellate P	g P m^{-3} d^{-1}	P
SEPP2	Sedimentation of diatom P	g P m^{-3} d^{-1}	P
SEPP3	Sedimentation of cyanobacteria P	g P m^{-3} d^{-1}	P
BUOYP1	Flagellate upward movement P	g P m^{-3} d^{-1}	P
BUOYP3	Cyanobacteria upward movement P	g P m^{-3} d^{-1}	P
SEDP	Deposition of detritus P	g P $m^{-3}d^{-1}$	P
tetp	Θ value in Arrhenius temperature function	n.u.	C
temp	Temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

kdo2i: new steady state condition for KDO2, function of DO & respiration, analytical solution

From the sediment-water intreface oxygen (DO) can penetrat into the sediment pore water by diffusion or actively being transportet into the sediment by ventilation pumping and sediment mixing by the benthic fauna. Further microbenthic algae through photosynthetis can produce DO in the sediment-water interface. DO is consumed in the sediment by bacterial respiration and chemical oxidation of reduced substances (Fe^{++}, H_2S) resulting in the O_2 concentration becomes 0 (normally 0-2 cm) below the sediment surface. In the model this depth is defined as KDO2. Assuming the DO produced by the microbenthic algae is delivered to the water, the below differential equation can be set up assuming a steady state condition:

$$0 = -difo2 * \frac{d^2 O_2}{dy^2} + DOconsum \text{ Where } 0<y<(KDO2_\infty) \tag{3.239}$$

Which by integration becomes:

$$\frac{d\ O_2}{dy} = \frac{DOconsum}{difo2} * y + a \tag{3.240}$$

Where a is a constant, which by using the border condition ($dO_{2/dy}$=0 at y=$KDO2_\infty$)) can be defined as:

$$a = -\frac{DOconsum}{dif02} * KDO2_\infty \Rightarrow$$

$$\frac{d\ O_2}{dy} = \frac{DOconsum}{difo2} * y - \frac{DOconsum}{difo2} * KDO2_\infty \tag{3.241}$$

Which by yet an integration gives:

$$O_2 = \frac{DOconsum}{2 * difo2} * y^2 - \frac{DOconsum}{difo2} * KDO2_\infty * y + b \tag{3.242}$$

Where b is a constant, which by using the border condition (O_2=0 at y=$KDO2_\infty$) can be defined as:

$$b = \frac{DOconsum}{2 * difno3} * KDO2_\infty{}^2 \Rightarrow$$

$$O_2 = \frac{DOconsum}{2 * difo2} * y^2 - \frac{DOconsum}{difo2} * KDO2_\infty * y + \frac{DOconsum}{difo2} * KDO2_\infty{}^2 \tag{3.243}$$

At the sediment surface y=0 the O_2 = DO =>

$$KDO2_\infty = \sqrt{2 * difo2 * \frac{DO}{DOconsum}} \Rightarrow \tag{3.244}$$

$KDO2_\infty$ is identical to *ko2i* in the model, however the DO consumption in the model is the sum of bacterial respiration (*reKDO2*), nitrification (rsnit) and a flux of reduced substances from the under laying sediment (*fsh2s*) to the layer with O_2. All the mentioned DO consuming processes has the unit (g $m^{-2}d^{-1}$) and therefore has to be divided with the DO penetration from the previous time step t ($KDO2_t$). A conversion factor for O_2:N of 4.57 g O_2:g NH_4-N is used and a conversion factor for O_2:S of 2 g O_2 : H_2S-S is used.

The diffusion or rather transport of oxygen into the sediment is dependent of the activity of the benthic infauna. Their activity is linked to the DO concentration, at low DO (below 2 g m^{-3}) the activity will decrease caused by increased mortality. The constant *difO2* is therefore multiplied by an oxygen function (1+sqdo).

$$kdo2i = \sqrt{2 * DO * \frac{difo2 * (1 + sqdo) * KDO2_t}{(rsnit * 4.57 + reKDO2 + fsh2s * 2)}} \tag{3.245}$$

Where:

Name	Comment	Unit	Type*)
difo2	Vertical diffusion for O_2 in sediment, low fauna activity	m^2d^{-1}	C
DOconsum	Sediment O_2 consumption, layer (0-KDO2)	g O_2 $m^{-3}d^{-1}$	
y	Depth below sediment surface	m	
$KDO2_\infty$	DO penetration into the sediment, steady state=***kdo2i***	m	
$KDO2_t$	DO penetration into the sediment time step t=***KDO2***	m	
KDO2	DO penetration into the sediment	m	S
sqdo	DO dependend auxiliary	n.u.	A
rsnit	Nitrification in sediment layer (0-KDO2)	g N $m^{-2}d^{-1}$	P
reKDO2	DO consumption by bacteria layer (0-KDO2)	g O_2 $m^{-2}d^{-1}$	P1
fsh2s	Flux of SH2S from reduced sediment to layer (0-KDO2)	g S $m^{-2}d^{-1}$	P
DO	O_2 in water above sediment	g O_2 m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

reKDO2: Sediment mineralisation of SOC by DO, in layer KDO2, g O_2 m^{-2} d^{-1}

$$reKDO2 = \frac{KDO2}{kds} * minSOC * vo * sqdo \tag{3.246}$$

Where:

Name	Comment	Unit	Type*)
KDO2	DO penetration depth in sediment	m	S
kds	Depth of modelled sediment layer	m	C
minSOC	Mineralisation of organic in sediment	g C m^{-2} d^{-1}	P
vo	O_2 : C ration production, respiration, mineralisation	g O_2 g C $^{-1}$	C
sqdo	Oxygen function	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

3.5.2 Auxiliary (A) processes listed in alphabetic order

buoy1: N & P & light upward movement function, flagellate, n.u.

The upward movements of phytoflagellates are a function of the light regime and nutrient condition of the algae. If the internal N and P pools (N/C and P/C ratios in the algae) are small the function powNP1 will have a small but positive value resulting in an in sedbouNP1 being negative and the buoy1 becoming 0. At low powNP1 there will be no upward movements. At high powNP1values (high N/C and P/C ratio in the algae) sedbouNP1 become positive and the algae will move upward provided the light doze is below a value of kiz3.

buoy1=IF i≤kiz3
THEN MAX (0,sedbouNP1) (3.247)
ELSE 0

Where:

$$sedbuoNP1 = k2NP * (\frac{powNP1}{powNP1 + k3NP^{k1NP}} - 0.5) \tag{3.248}$$

And:

$$powNP1 = MIN(myp1, myn1)^{k1NP} \tag{3.249}$$

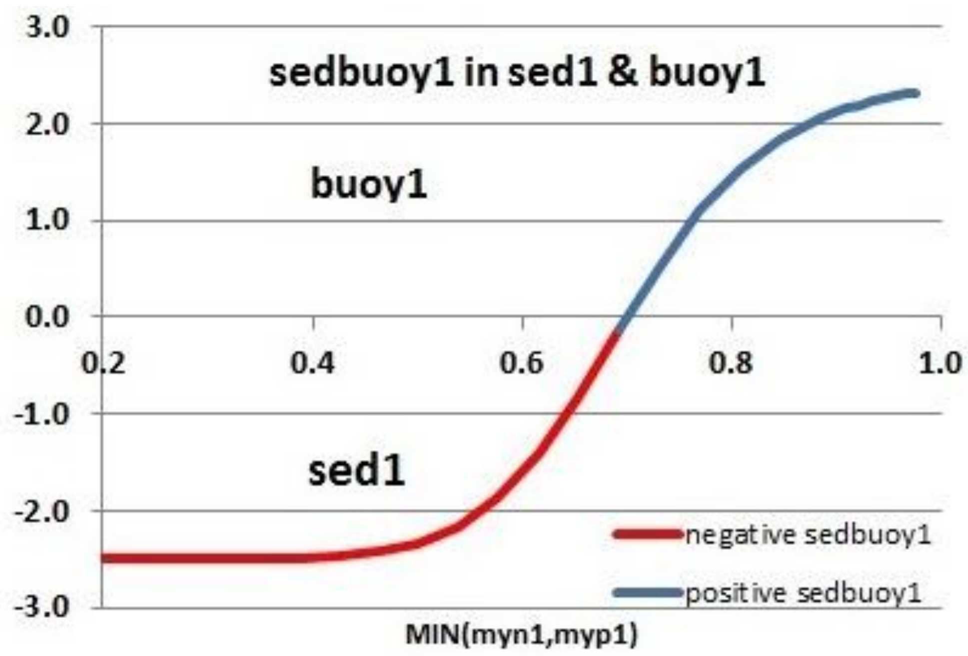

Figure 3.3 Figure Flagellates upward movement is dependent of positive values of sedboy1, which is dependent on a good N and P condition myn1 and myp1

Where:

Name	Comment	Unit	Type*)
kiz3	Light limit, buoyancy for PC1 & PC 3	mol photon $m^{-2}d^{-1}$	C
i	Photosynthetic Active Light (PAR) at top of layer	mol photon $m^{-2}d^{-1}$	A
k1NP	Exponent, sedimentation & buoyancy, PC1&PC3	n.u.	C
k2NP	Factor, sedimentation & buoyancy, PC1 & PC3	n.u.	C
k3NP	Shift from sedimentation to buoyancy, PC1 & PC3	n.u.	C
powNP1	Power function limiting nutrient, Flagellate (PC1)	n.u.	A
myn1	Nitrogen function flagellates	n.u.	A
myp1	Phosphorous function flagellates	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

buoy3: N & P & light upward movement function, cyanobacteria, n.u.

The upward movement of cyanobacteria is a function of the light regime and nutrient condition of the bacteria. If the internal N and P pools (N/C and P/C ratios in the bacteria) are small the function powNP3 will have a small but positive value resulting in an in sedbouNP3 being negative and the buoy1 becoming 0. At low powNP3 there will be no upward movements. At high powNP3 values (high N/C and P/C ratio in the bacteria) sedbouNP3 become positive and the algae will move upward provided the light doze is below a value of *kiz3*.

$$buoy3 = IF\ \ i \le kiz3\ THEN\ MAX(0, sedbouNP3)\ ELSE\ 0 \tag{3.250}$$

Where:

$$sedbuoNP3 = k2NP * (\frac{powNP3}{powNP3 + k3NP^{k1NP}} - 0.5) \tag{3.251}$$

And:

$$powNP3 = MIN(myp3, myn3)^{k1NP} \tag{3.252}$$

Where:

Name	Comment	Unit	Type*)
kiz3	Light limit, buoyancy for PC1 & PC 3	mol photon $m^{-2}d^{-1}$	C
i	Photosynthetic Active Light (PAR) at top of layer	mol photon $m^{-2}d^{-1}$	A
k1NP	Exponent, sedimentation& buoyancy, PC1&PC3	n.u.	C
k2NP	Factor, sedimentation & buoyancy, PC1 & PC3	n.u.	C
k3NP	Shift from sedimentation to buoyancy, PC1 & PC3	n.u.	C
powNP3	Power function limiting nutrient, cyanobacteria	n.u.	A
myn3	Nitrogen function cyanobacteria	n.u.	A
myp3	Phosphorous function cyanobacteria	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

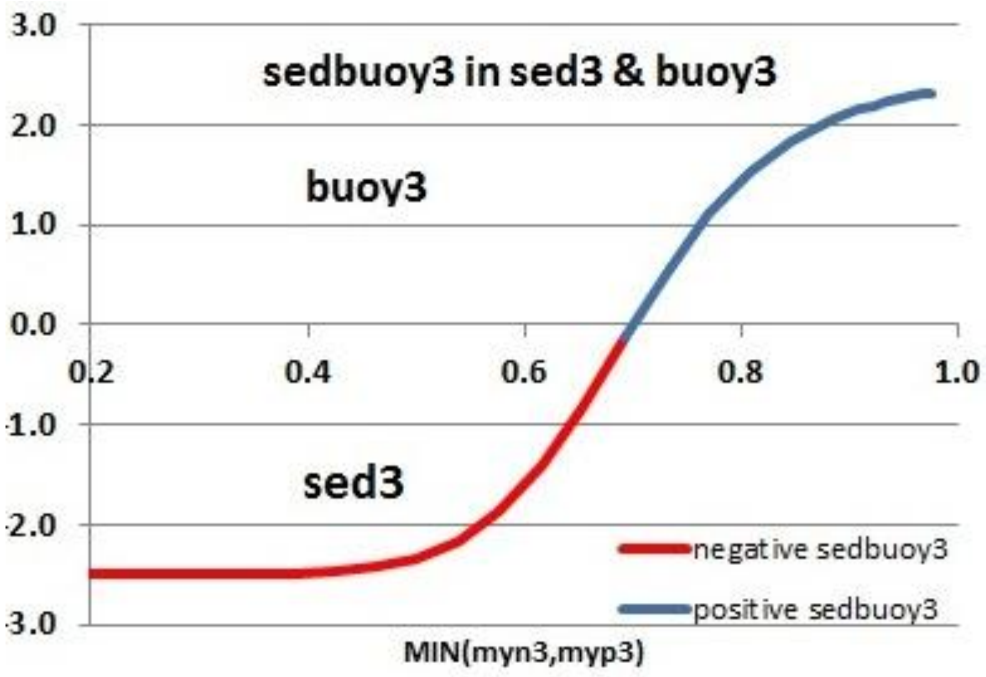

Figure 3.4 Cyanobaterial upward movement is dependent of positive values of sedboy3, which is dependent on a good N and P condition myn3 and myp3.

CSAIR: O_2 saturation in water, relative to PSU & temp., g O_2 m^{-3}

A built in function in MIKE ECO Lab calculates the O_2 saturation relative to salinity and temperature. In this template the O2 saturation defined by (Weiss 1970) is used:

$$CSAIR = \text{OXYGENSATURATION\_WEISS}(S,T) \tag{3.253}$$

Or:

$$CSAIR = \frac{e^{a}}{0.69997} \tag{3.254}$$

Where:

$$a = -173.4292 + 249.6339 + \frac{100}{T+273.15} + 143.2483 * \log\left(\frac{T+273.15}{100}\right) - 21.8493 * \left(\frac{T+273.15}{100}\right) + S * \left(-0.033096 + 0.014259 * \frac{T+273.15}{100} - 0.0017 * \left(\frac{T+273.15}{100}\right)^{2}\right) \tag{3.255}$$

In other templates the below equation is used.

$$CSAIR = \text{OXYGENSATURATION}(S,T) \tag{3.256}$$

Or:

$$CSAIR = 14.65 - 0\,0841 \cdot S + T*(0.00256 \cdot S - 0.41022 + T*(0.007991 - 0.0000374*S - 0.000077774*T)) \tag{3.257}$$

Where:

Name	Comment	Unit	Type*)
S	Salinity	PSU	F
T	Temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

dndc: N:C ration, detritus, g N g C^{-1}

$$dndc = \frac{DN}{DC} \tag{3.258}$$

Where:

Name	Comment	Unit	Type*)
DN	Detritus N	g N m^{-3}	S
DC	Detritus C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

dnm3: denitrification in sediment, corrected for temperature

$$dnm3 = demax * tetn^{T-20} \tag{3.259}$$

Where:

Name	Comment	Unit	Type*)
Demax	Max. denitrification rate in sediment at 20 °C	g N m^{-2}d^{-1}	C
Tetn	Ө value in Arrhenius temperature function	n.u	C
T	Temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

doc$_{monod}$: UV radiation Monod relation for photo oxidation, n.u.

$$DOC_{monod} = \frac{i - doc_{ie}}{i - doc_{ie} + doc_{ik}} \tag{3.260}$$

Where:

Name	Comment	Unit	Type*)
I	Solar radiation (PAR) in actual water column layer	µmol photon m^{-2} s^{-1}	A
doc$_{ie}$	min PAR light, CDOC photo oxidation	µmol photon m^{-2} s^{-1}	C
doc$_{ik}$	PAR half saturation photo oxidation of CODC	µmol photon m^{-2} s^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

dpdc: P:C ration, detritus, g P g C^{-1}

$$dndc = \frac{DP}{DC} \tag{3.261}$$

Where:

Name	Comment	Unit	Type*)
DP	Detritus P	g P m^{-3}	S
DC	Detritus C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

dsidc: Si:C ration, detritus, g Si g C^{-1}

$$dSidc = \frac{DSi}{DC} \tag{3.262}$$

Where:

Name	Comment	Unit	Type*)
DSi	Detritus Si	g Si m^{-3}	S
DC	Detritus C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

$\mathbf{DT_{day}}$: AD time step (and not HD time step!) in days, d step^{-1}

$$DT_{day} = \frac{DT}{86400} \tag{3.263}$$

Where:

Name	Comment	Unit	Type*)
DT	Time step in sec.	Sec. step^{-1}	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

eta: Vertical light attenuation, m^{-1}

It is possible to calculate the vertical light attenuation based on light extinction constants or use the expression formulated by (Effer 1988; Kirk 2000) splitting the light attenuation into a light absorption and a scattering of light.

The surface area of the particles are important for the optical properties, as small particle have a larger surface area, they also have a higher vertical light extinction constant or a higher light scattering constant. In general the optical properties of particulate matter are proportional to the surface area of the particles in the water. In the equation for **eta1** and scattering **scatw** 3 size classes of inorganic matter (ss1-ss3) are defined in g m^{-3}. The mass is not an ideal measure for inorganic matter in relation to the optical properties; therefore the mass of ss1-ss3 is related to a particle size with a diameter of 10 µm, by multiplication of a factor (10/diass$_x$). Small particles below 10 µm thereby will be assigned a higher light extinction constant, or absorption and scattering constants, whereas larger particles will be assigned smaller constants.

The shape of the particles may be anything from a ball to spherical cone; therefore the correction factor (10/diass$_x$) should only be regarded as guidelines to be used if no measured data exists.

In the present MIKE ECO Lab template resuspension is not included therefore the light extinction not included dynamically in the model often is put into the background light extinction (bla) and the light extinction form suspended matter is the light extinction from marine earth works. The user should in this case be aware that the background extinction varies in time and space especially in coastal waters.

$$\text{eta}= IF\ Keta > 0\ THEN\ eta2\ ELSE\ eta1 \tag{3.264}$$

Where:

$$\text{eta1} = pla * CH + dla * DC + cla * CDOC + sla * 10 * \left(\frac{ss1}{diass1} + \frac{ss2}{diass2} + \frac{ss3}{diass3}\right) + bla \tag{3.265}$$

$$\text{eta2} = \sqrt{absw^2 + 0.256 * absw * scatw}$$

And:

$$\text{absw}= pla_a * CH + dla_a * DC + cla_a * CDOC + sla_a * 10 * \left(\frac{ss1}{diass1} + \frac{ss2}{diass2} + \frac{ss3}{diass3}\right) + bla_a \tag{3.266}$$

$$\text{scatw}= bkch * CH^{ekch} + bkss * (\frac{10*SS1}{diass1} + \frac{10*ss2}{diass2} + \frac{10*ss3}{diass3})^{ekss}$$

The scatter of light (scatw) is defined as a power function of phytoplankton chlorophyll, (Morel A. 1980, Prieur L. & S. Sathyendranath 1981). The authours found a value range for bkch of 0.12-0.4 m^2 mg^{-1} & ekch 0.63. The scatter by phytoplankton is dependent on cell size. The cell size tends to be smaller at low chlorophyll concentrations, where the plankton typically is nutrient limited (Yentsch C.S., D. A. Phinney 1989).

Lund-Hansen L.C. 2004 found chlorophyll in average to be responsible for 41% of the scattering in the nearby Århus Bay using a fixed specific chlorophyll scattering of 0.239 m^2 mg^{-1} measured in New Zeland coastal waters (Pfannkuche F. 2002).

Please note that the mentioned scatter constants should be converted from m^2mg^{-1} to m^2g^{-1} before being used in this model.

Where:

Name	Comment	Unit	Type*)
Keta	Constant for choice of eta estimate	n.u.	C
eta1	Function vertical light attenuation, extinction constants	m^{-1}	A
eta2	Function vertical light attenuation, absorption & scattering	m^{-1}	A
pla	Chlorophyll light extinction constant	m^2 g^{-1}	C
CH	Chlorophyll concentration	g m^{-3}	S
dla	Detritus light extinction constant	m^2 g^{-1}	C
DC	Detritus C	g m^{-3}	S
cla	CDOC light extinction constant	m^2 g^{-1}	C
CDOC	Coloured refractory DOC	g m^{-3}	S
sla	Inorganic matter light extinction constant (ϴ=10 μm)	m^2 g^{-1}	C
ss1	Inorganic matter, s e class 1	g m^{-3}	F
ss2	Inorganic matter, size class 2	g m^{-3}	F
ss3	Inorganic matter, size class 3	g m^{-3}	F
diass1	Diameter of inorganic matter, size class 1	μm	C
diass2	Diameter of inorganic matter, size class 2	μm	C

Name	Comment	Unit	Type*)
diass2	Diameter of inorganic matter, size class 2	µm	C
bla	Background light extinction	m^{-1}	C
absw	Light absorption in layer	m^{-1}	A
scatw	Light scattering in layer	m^{-1}	A
pla_a	Chlorophyll light absorption constant	$m^2\ g^{-1}$	C
dla_a	Detritus light absorption constant	$m^2\ g^{-1}$	C
cla_a	CDOC light absorption constant	$m^2\ g^{-1}$	C
sla_a	Inorganic matter light absorption constant (ϴ=10 µm)	$m^2\ g^{-1}$	C
bla_a	Background light absorption	m^{-1}	C
bkch	Chlorophyll scattering constant	$m^2\ g^{-1}$	C
ekch	Chlorophyll scattering exponent	n.u.	C
bkss	Inorganic matter scattering constant	$m^2\ g^{-1}$	C
ekss	Inorganic matter scattering exponent	n.u.	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

fiz: Light factor for flagellates and cyanobacteria (PC1 & PC3) sedimentation, n.u.

$$fiz = fiz1 * fiz2 \tag{3.267}$$

Where:

$$\begin{aligned} fiz1 &= IF\ i > kiz1\ THEN\ 3\ ELSE\ 1 \\ fiz2 &= IF\ i > kiz2\ THEN\ 1\ ELSE\ 0 \end{aligned} \tag{3.268}$$

Where:

Name	Comment	Unit	Type*)
fiz1	1. Help factor for PC1 & PC3 sedimentation	n.u.	A
fiz2	2. Help factor for PC1 & PC3 sedimentation	n.u.	A
i	Light at top of actual water layer	mol photon $m^{-2}d^{-1}$	A
kiz1	Light limit for 3 X sedimentation rate of PC1 & PC3	mol photon $m^{-2}d^{-1}$	C
kiz2	Light limit for 1 X sedimentation rate of PC1 & PC3	mol photon $m^{-2}d^{-1}$	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

fiz1: 1. Help factor for PC1 & PC3 sedimentation, n.u.

See under auxiliary fiz, Equation (3.18) and Equation (3.29).

fiz2: 2. Help factor for PC1 & PC3 sedimentation, n.u.

See under auxiliary fiz, Equation (3.18) and Equation (3.29).

fn3a: Denitrification, DO dependency in water column, n.u.

$$fn3a = \frac{ksb}{ksb + DO} \tag{3.269}$$

Where:

Name	Comment	Unit	Type*)
ksb	Denitrification Half saturation conc. DO	g O_2m^{-3}	C
DO	Oxygen concentration	g O_2m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

fp3sal: Function for cyanobacteria dependency (death & growth) of salinity, n.u.

$$fp3sa = IF\ S < kp3opti\ THEN\ 1\ ELSE\ e^{-kp3sal1*(S-kp3sal2)} \tag{3.270}$$

Where:

Name	Comment	Unit	Type*)
kp3opti	Highest salinity for optimum cyanobacteria growth	PSU	C
kp3sal1	Cyanobacteria growth salinity dependency coefficient	PSU^{-1}	C
kp3sal2	Cyanobacteria growth salinity dependency constant	PSU	C
S	Salinity	PSU	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

fsa: Salinity function for reduction of SO_4 to H_2S, n.u.

$$fsa = IF\ S > ksa\ THEN\ 1\ ELSE\ 0 \tag{3.271}$$

Where:

Name	Comment	Unit	Type*)
ksa	Minimum salinity for SO_4 reduction	PSU	C
S	Salinity	PSU	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

i: Solar radiation (PAR) in actual water column layer (j), mol photon $m^{-2}d^{-1}$

If the surface water temperature >0.2 °C the water is assumed ice free and i_0 will be the light (PAR) reaching the surface of the water.

If the temperature is below 0.2 °C ice is assume on the water and only 10% of i_0 is assumed to penetrate the ice cover.

In a more general form the light (PAR) distribution in the different water layer can be expressed as:

$$i = i_o * e^{\sum_j^0 -eta_{0-j} * dz_{\ 0-j}} \tag{3.272}$$

MIKE ECO Lab has an builtin function (LAMBERT_BEER_1) calculate the light (PAR) at the top of each water layer.

The average light (PAR) in a water layer can be expressed as:

$$i = \frac{1 - e^{-eta*dz}}{eta * dz} * LAMBERT\_BEER\_1(i_0, dz, eta) \tag{3.273}$$

Where:

Name	Comment	Unit	Type*)
i_o	Solar (PAR) radiation at water surface	mol photon $m^{-2}d^{-1}$	F
$eta_{0\text{-}j}$	Light attenuation (Kd) in layers 0 to j	m^{-1}	
$dz_{0\text{-}j}$	Height of layer 0 to j	m	
eta	Light attenuation (Kd) in actual layer	m^{-1}	A
dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

ik1: Temperature corrected Light saturation for flagellates, mol photon $m^{-2}d^{-1}$

$$ik1 = alfa1 * teti^{T-20} \tag{3.274}$$

Where:

Name	Comment	Unit	Type*)
alfa1	Light saturation at 20 °C for flagellates	mol photon $m^{-2}d^{-1}$	C
teti	ϴ value Arrhenius expression	n.u	C
T	temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

ik2: Temperature corrected Light saturation for diatoms, mol photon $m^{-2}d^{-1}$

$$ik2 = alfa2 * teti^{T-20} \tag{3.275}$$

Where:

Name	Comment	Unit	Type*)
Alfa2	Light saturation at 20 °C for diatoms	mol photon $m^{-2}d^{-1}$	C
teti	ϴ value Arrhenius expression	n.u	C
T	temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

ik3: Temperature corrected Light saturation for cyanobacteris, mol photon $m^{-2}d^{-1}$

$$ik3 = alfa3 * teti^{T-20} \tag{3.276}$$

Where:

Name	Comment	Unit	Type*)
Alfa3	Light saturation at 20 °C for cyanobacteria	mol photon $m^{-2}d^{-1}$	C
teti	ϴ value Arrhenius expression	n.u	C
T	temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

ksd: Sedimentation rate detritus, d^{-1}

The sedimentation of a particle is not allowed to pass through several water layers in one time step (DT_{day} time step in d). The sedimentation in one times step is therefore restricted to a maximum of dz.

This restriction may led to an underestimation of sedimentation in 3-D set ups with a fine vertical resolution using small dz. However by not imposing the below restriction in sedimentation will potentially generate mass balance errors.

$$ksd = IF\ dz \leq sevd * DT_{day}\ THEN\ \frac{dz}{DT_{day}}\ ELSE\ sevd \tag{3.277}$$

Where:

Name	Comment	Unit	Type*)
dz	Height of actual water layer	m	F
DT_{day}	AD time step	d $step^{-1}$	C
sevd	Sedimentation rate	m d^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mgpc: Temperature, O_2 & food corrected max. grazing rate by zooplankton, d^{-1}

$$mgpc = kgrb * tetz^{T-20} * \frac{sqdo}{1 + e^{kgrm - kgrs*(kedib1*PC1 + kedib2*PC2 + kedib3*PC3)}} \tag{3.278}$$

Where:

Name	Comment	Unit	Type*)
kgrb	Max. specific grazing rate, zooplankton	d^{-1}	C
tetz	ϴ in Arrhenius temp. relation of zooplankton grazing	n.u.	C
T	Temperature	°C	F
sqdo	DO function	n.u.	A
kgrm	Zooplankton 0. order dependency of grazing on plankton	n.u.	C
kgrs	Zooplankton 1. order dependency of grazing on plankton	n.u.	C
kedib1	Edible fraction of Flagellate	n.u.	C
kedib2	Edible fraction of Flagellate	n.u.	C

Name	Comment	Unit	Type*)
kedib3	Edible fraction of Flagellate	n.u.	C
PC1	Flagellate C	g C m^{-3}	S
PC2	Diatom C	g C m^{-3}	S
PC3	Cyanobacteria C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mnl1: Nutrient dependent death factor, flagellate, n.u.

The death factor is 1 with flagellate having high internal N:C and P:C ratios, but up to 5 in a nutrient stressed condition (low N:C and P:C ratios).

$$mnl1 = MIN(\frac{\left(\frac{1}{myn1} + \frac{1}{myp1}\right)}{2}, 5) \tag{3.279}$$

Where:

Name	Comment	Unit	Type*)
myn1	Nitrogen function flagellate	n.u	A
myp1	Phosphorous function flagellate	n.u	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mnl2: Nutrient dependent death factor, diatoms, n.u.

The death factor is 1 with diatoms having high internal N:C, P:C and Si:C ratios, but up to 5 in a nutrient stressed condition (low N:C, P:C or Si:C ratios).

$$mnl2 = MIN(\frac{\left(\frac{1}{myn2} + \frac{1}{myp2} + \frac{1}{mys2}\right)}{3}, 5) \tag{3.280}$$

Where:

Name	Comment	Unit	Type*)
myn2	Nitrogen function diatoms	n.u	A
myp2	Phosphorous function diatoms	n.u	A
mys2	Si function, diatoms	n.u	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mnl3: Nutrient dependent death factor, cyanobacteria, n.u.

The death factor is 1 with cyanobacteria having high internal N:C and P:C ratios, but up to 5 in a nutrient stressed condition (low N:C and P:C ratios).

$$mnl3 = MIN(\frac{\left(\frac{1}{myn3} + \frac{1}{myp3}\right)}{2}, 5) \tag{3.281}$$

Where:

Name	Comment	Unit	Type*)
myn3	Nitrogen function cyanobacteria	n.u	A
myp3	Phosphorous function cyanobacteria	n.u	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mntp1: N, P & temperature corrected max. net growth rate, flagellates d^{-1}

$$mntp1 = myte1 * \frac{2}{\left(\frac{1}{myn1} + \frac{1}{myp1}\right)} \tag{3.282}$$

Where:

Name	Comment	Unit	Type*)
myte1	Specific growth ,temperature regulated, flagellates	n.u.	A
myn1	Nitrogen function flagellates	n.u.	A
myp1	Phosphorous function flagellates	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mntp2: N, P & temperature corrected max. net growth rate, diatoms d^{-1}

$$mntp2 = myte2 * \frac{3}{\left(\frac{1}{myn2} + \frac{1}{myp2} + \frac{1}{mys2}\right)} \tag{3.283}$$

Where:

Name	Comment	Unit	Type*)
myte2	Specific growth ,temperature regulated, diatoms	n.u.	A
myn2	Nitrogen function diatoms	n.u.	A
myp2	Phosphorous function diatoms	n.u.	A
mys2	Silicate function diatoms	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mntp3: N, P & temperature corrected max. net growth rate, cyanobacteria d^{-1}

$$mntp3 = myte3 * \frac{2}{\left(\frac{1}{myn3} + \frac{1}{myp3}\right)} \tag{3.284}$$

Where:

Name	Comment	Unit	Type*)
myte3	Specific growth ,temperature regulated, cyanobacteria	n.u.	A
myn3	Nitrogen function cyanobacteria	n.u.	A
myp3	Phosphorous function cyanobacteria	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mspc1: Sedimentation rate flagellate phytoplankton, d^{-1}

The sedimentation of a particle is not allowed to pass through several water layers in one time step (DT$_{day}$ time step in d). The sedimentation in one times step is therefore restricted to a maximum of dz.

$$mspc1 = IF\ dz \leq seve1 * DT_{day}\ THEN \frac{dz}{DT_{day}}\ ELSE\ seve1 \tag{3.285}$$

This restriction may lead to an underestimation of sedimentation in 3D set-ups with a fine vertical resolution using small dz. However, by not imposing the above restriction in sedimentation will potentially generate mass balance errors.

Where:

Name	Comment	Unit	Type*)
seve1	Sedimentation rate flagellate	m d^{-1}	C
DT_{day}	**AD** time step (and not HD time step!) in days	d	A
dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mspc2: Sedimentation rate diatom phytoplankton, d^{-1}

The sedimentation of a particle is not allowed to pass through several water layers in one time step (DT_{day} time step in d). The sedimentation in one times step is therefore restricted to a maximum of dz.

$$mspc2 = IF\ dz \leq seve2 * DT_{day}\ THEN \frac{dz}{DT_{day}}\ ELSE\ seve2 \tag{3.286}$$

This restriction may lead to an underestimation of sedimentation in 3D set-ups with a fine vertical resolution using small dz. However, by not imposing the above restriction in sedimentation will potentially generate mass balance errors.

Where:

Name	Comment	Unit	Type*)
seve2	Sedimentation rate diatoms	m d^{-1}	C
DT_{day}	**AD** time step (and not HD time step!) in days	d	A
dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mspc3: Sedimentation rate cyanobacteria, d^{-1}

The sedimentation of a particle is not allowed to pass through several water layers in one time step (DT_{day} time step in d). The sedimentation in one times step is therefore restricted to a maximum of dz.

$$mspc3 = IF\ dz \leq seve3 * DT_{day}\ THEN \frac{dz}{DT_{day}}\ ELSE\ seve3 \tag{3.287}$$

This restriction may lead to an underestimation of sedimentation in 3D set-ups with a fine vertical resolution using small dz. However, by not imposing the above restriction in sedimentation will potentially generate mass balance errors.

Where:

Name	Comment	Unit	Type*)
seve3	Sedimentation rate cyanobacteria	m d^{-1}	C
DT_{day}	**AD** time step (and not HD time step!) in days	d	A
dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myfi1: Light function Flagellate, n.u.

Equation (3.288) is an analytical solution of the integrated light available for production of flagellates in the water column.

Where:

$$myfi1 = (zk1 + \frac{i}{ik1 * eta} * (e^{-eta*zk1} - e^{-eta*dz}))/dz \tag{3.288}$$

Where:

Name	Comment	Unit	Type*)
zk1	Light availability flagellate production	m	A
ik1	Light saturation flagellate temperature corrected	mol photon $m^{-2}d^{-1}$	A
eta	Vertical light attenuation	m^{-1}	A
i	Photosynthetic Active Light (PAR) of layer	mol photon $m^{-2}d^{-1}$	A
dz	Height of actual layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myfi2: Light function diatom, n.u.

Equation (3.289) is an analytical solution of the integrated light available for production of flagellates in the water column.

$$myfi2 = (zk2 + \frac{i}{ik2 * eta} * (e^{-eta*zk2} - e^{-eta*dz}))/dz \tag{3.289}$$

Where:

Name	Comment	Unit	Type*)
zk2	Light availability diatom production	m	A
ik2	Light saturation diatome temperature corrected	mol photon $m^{-2}d^{-1}$	A
eta	Vertical light attenuation	m^{-1}	A
i	Photosynthetic Active Light (PAR) of layer	mol photon $m^{-2}d^{-1}$	A
dz	Height of actual layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myfi3: Light function cyanobacteria, n.u.

Equation (3.290) is an analytical solution of the integrated light available for production of flagellates in the water column.

$$myfi3 = (zk3 + \frac{i}{ik3 * eta} * (e^{-eta*zk3} - e^{-eta*dz}))/dz \tag{3.290}$$

Where:

Name	Comment	Unit	Type*)
zk3	Light availability cyanobacteria production	m	A
ik3	Light saturation cyanobacteria temp. corrected	mol photon $m^{-2}d^{-1}$	A
eta	Vertical light attenuation	m^{-1}	A
i	Photosynthetic Active Light (PAR) of layer	mol photon $m^{-2}d^{-1}$	A
dz	Height of actual layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myn1: Nitrogen function flagellates, n.u.

$$myn1 = \frac{PN1/PC1 - pnmi}{(pnma - pnmi)} \tag{3.291}$$

Where:

Name	Comment	Unit	Type*)
PC1	Flagellate phytoplankton C	g C m^{-3}	S
PN1	Flagellate phytoplankton N	g N m^{-3}	S
pnmi	Minimum N:C ratio in phytoplankton	g N g C^{-1}	C
pnma	Maximum N:C ratio in phytoplankton	g N g C^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myn2: Nitrogen function Diatoms, n.u.

$$myn2 = \frac{\frac{PN2}{PC2} - psmi * pnsi}{(pnma - psmi * pnsi)} \tag{3.292}$$

Where:

Name	Comment	Unit	Type*)
PC2	Diatom phytoplankton C	g C m^{-3}	S
PN2	Diatom phytoplankton N	g N m^{-3}	S
psmi	Minimum Si:C ratio in diatoms	g Si g C^{-1}	C
pnsi	Minimum N:Si ratio in diatoms	g N g Si^{-1}	C
pnma	Maximum N:C ratio in phytoplankton	g N g C^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myn3: Nitrogen function cyanobacteria, n.u.

$$myn3 = \frac{PN3/PC3 - pnmi}{(pnma - pnmi)} \tag{3.293}$$

Where:

Name	Comment	Unit	Type*)
PC3	Cyanobacteria C	g C m^{-3}	S
PN3	Cyanobacteria N	g N m^{-3}	S
pnmi	Minimum N:C ratio in phytoplankton / cyanobacteria	g N g C^{-1}	C
pnma	Maximum N:C ratio in phytoplankton / cyanobacteria	g N g C^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myp1: Phosphorous function flagellates, n.u.

$$myp1 = \frac{(kc + ppma - ppmi) * (\frac{PP1}{PC1} - ppmi)}{(ppma - ppmi) * (kc + \frac{PP1}{PC1} - ppmi)} \tag{3.294}$$

Where:

Name	Comment	Unit	Type*)
PC1	Flagellate phytoplankton C	g C m^{-3}	S
PP1	Flagellate phytoplankton P	g P m^{-3}	S
ppmi	Minimum P:C ratio in phytoplankton	g P g C^{-1}	C
ppma	Maximum P:C ratio in phytoplankton	g P g C^{-1}	C
kc	Half saturation concentration for phytoplankton P	g P g C^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myp2: Phosphorous function diatoms, n.u.

$$myp2 = \frac{(kc + ppma - ppmi) * (\frac{PP2}{PC2} - ppmi)}{(ppma - ppmi) * (kc + \frac{PP2}{PC2} - ppmi)} \tag{3.295}$$

Where:

Name	Comment	Unit	Type*)
PC2	Flagellate phytoplankton C	g C m^{-3}	S
PP2	Flagellate phytoplankton P	g P m^{-3}	S
ppmi	Minimum P:C ratio in phytoplankton	g P g C^{-1}	C

Name	Comment	Unit	Type*)
ppma	Maximum P:C ratio in phytoplankton	g P g C^{-1}	C
kc	Half saturation concentration for phytoplankton P	g P g C^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myp3: Phosphorous function cyanobacteria, n.u.

$$myp3 = \frac{(\frac{kc}{ppma} * p3pma + p3pma - p3pmi) * (\frac{PP3}{PC3} - p3pmi)}{(p3pma - p3pmi) * (\frac{kc}{ppma} * p3pma + \frac{PP3}{PC3} - p3pmi)} \tag{3.296}$$

Where:

Name	Comment	Unit	Type*)
PC3	Cyanobacteria C	g C m^{-3}	S
PP3	Cyanobacteria P	g P m^{-3}	S
ppmi	Minimum P:C ratio in phytoplankton	g P g C^{-1}	C
ppma	Maximum P:C ratio in phytoplankton	g P g C^{-1}	C
kc	Half saturation conc. for phytoplankton	g P g C^{-1}	C
p3pma	Maximum P:C ratio in cyanobacteria	g P g C^{-1}	C
p3pmi	Minimum P:C ratio in cyanobacteria	g P g C^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

mys2: Si function, diatoms, n.u

$$mys2 = \frac{\frac{PSi2}{PC2} - psmi}{(psma + psmi)} \tag{3.297}$$

Where:

Name	Comment	Unit	Type*)
PC2	Diatom phytoplankton C	g C m^{-3}	S
PSi2	Diatom phytoplankton Si	g Si m^{-3}	S
psmi	Minimum Si:C ratio in diatoms	g Si g C^{-1}	C
psma	Maximum Si:C ratio in diatoms	g Si g C^{-1}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myte1: Flagellate specific temperature corrected growth, d^{-1}

$$myte1 = mym1 * tet1^{T-20} \tag{3.298}$$

Where:

Name	Comment	Unit	Type*)
mym1	Max. specific net growth at 20 °C, flagellates	d^{-1}	C
tet1	ϴ value in Arrhenius relation, flagellate temp. relation	n.u.	C
T	Temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myte2: Diatom specific temperature corrected growth, d^{-1}

Smoot_T is a function that makes a smoothing or rolling average of the daily surface insolation (PAR) over a number of days ($T2_{days}$) defined by the user, see auxiliary Smoot_T, Equation (3.318). This smoothing or rolling average is used to adjust the reference temperature of the max. specific growth rate of the diatoms.

The seasonal variation of temperature in the water follow the seasonal variation of the light (PAR) with a delay (1 month) depending of the amount of water (depth) to be heated up. In spring the temperature will be low compared to the daily PAR doze whereas in fall the temperature will be high compared to the daily PAR doze. The diatom reference temperature therefor has to change over the season.

In spring the diatoms blooms at low temperatures and disappear when the silicate is used up. During summer some silicate will be available however the diatom community has changed and another higher reference temperature is needed. In fall a secondary diatom bloom is sometimes seen after the erosion of the pycnocline. The diatom community is again adapted to lower temperatures and decreasing PAR.

Introducing Smoot_T is an attempt to make a seasonal adjustment of the specific growth with the water temperature and light as forcing.

$$myte2 = mym2 * tet2^{T-6-Smoot\_T} \tag{3.299}$$

Where:

Name	Comment	Unit	Type*)
mym2	Max. specific net growth at 6-10 °C, Diatoms	d^{-1}	C
tet2	Θ value in Arrhenius relation, diatom temp. relation	n.u.	C
Smoot_T	Correction of reference temp. for diatoms	°C	A
T	Temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

myte3: Cyanobacteria specific temperature corrected growth, d^{-1}

$$myte3 = mym3 * tet3^{T-20} \tag{3.300}$$

Where:

Name	Comment	Unit	Type*)
mym3	Max. specific net growth at 20 °C, cyanobacteria	d^{-1}	C
tet3	Θ value in Arrhenius relation, cyanobacteria temp. relation	n.u.	C
T	Temperature	°C	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

nfix1: Function for N fixation (1 if PSU≤12 else 0), n.u.

$$nfix1 = IF\ S \leq 12\ THEN\ 1\ ELSE\ 0 \tag{3.301}$$

Where:

Name	Comment	Unit	Type*)
S	Salinity	PSU	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

nfix2: Function for N fixation (1 if 0≤PSU≤10 else 0-1), n.u.

$$nfix2 = IF\ S \geq 12\ THEN\ (1 - \frac{S-10}{12-10})\ ELSE\ 1 \tag{3.302}$$

Where:

Name	Comment	Unit	Type*)
S	Salinity	PSU	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

pn1pc1: N:C ration flagellates g N g C^{-1}

$$pn1pc1 = \frac{PN1}{PC1} \tag{3.303}$$

Where:

Name	Comment	Unit	Type*)
PN1	Flagellate phytoplankton N	g N m^{-3}	S
PC1	Flagellate phytoplankton C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

pn2pc2: N:C ration diatomes g N g C^{-1}

$$pn2pc2 = \frac{PN2}{PC2} \tag{3.304}$$

Where:

Name	Comment	Unit	Type*)
PN2	Diatom phytoplankton N	g N m^{-3}	S
PC2	Diatom phytoplankton C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

pn3pc3: N:C ration cyanobacteria g N g C^{-1}

$$pn3pc3 = \frac{PN3}{PC3} \tag{3.305}$$

Where:

Name	Comment	Unit	Type*)
PN3	Cyanobacteria N	g N m^{-3}	S
PC3	Cyanobacteria C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

powNP1: Power function for limiting nutrient, Flagellate (PC1), n.u.

See under auxiliary sed1, Equation (3.18).

powNP3: Power function for limiting nutrient, cyanobacteria (PC3), n.u.

See under auxiliary sed3, Equation (3.29).

pp1pc1: P:C ration flagellates g P g C^{-1}

$$pp1pc1 = \frac{PP1}{PC1} \tag{3.306}$$

Where:

Name	Comment	Unit	Type*)
PP1	Flagellate phytoplankton P	g P m^{-3}	S
PC1	Flagellate phytoplankton C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

pp2pc2: P:C ration diatomes g P g C^{-1}

$$pp2pc2 = \frac{PP2}{PC2} \tag{3.307}$$

Where:

Name	Comment	Unit	Type*)
PP2	Diatom phytoplankton P	g P m^{-3}	S
PC2	Diatom phytoplankton C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

pp3pc3: P:C ration cyanobacteria g P g C^{-1}

$$pp3pc3 = \frac{PP3}{PC3} \tag{3.308}$$

Where:

Name	Comment	Unit	Type*)
PP3	Cyanobacteria P	g P m^{-3}	S
PC3	Cyanobacteria C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

psi2pc2: Si:C ration diatomes g Si g C^{-1}

$$psi2pc2 = \frac{PSi2}{PC2} \tag{3.309}$$

Where:

Name	Comment	Unit	Type*)
PSi2	Diatom Si	g Si m^{-3}	S
PC2	Diatom phytoplankton C	g C m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

rd: Relative daylength, f(month, day,latitude), n.u.

A built in function in MIKE ECO Lab that returns a value for relative day length. The value equals 1 at equinox (when day and night have same length).

$$rd = RELATIVE\_DAYLENGTH(month, day, latitude) \tag{3.310}$$

sedbouNP1: sedimentation & buoyance N&P function, Flagellate, n.u

Please see auxiliary sed1, Equation (3.18), or buoy1, Equation (3.19)

sedbouNP3: sedimentation & buoyance N&P function, cyanobacteria, n.u

Please see auxiliary sed3, Equation (3.29), or buoy3, Equation (3.30).

sed1: N&P sedimentation function, Flagellate, n.u.

The sedimentation (downward movement) of the algae is increased by low internal N/C and P/C ratios of the algae. powNP1 will be positive but small and sedbuoNP1 becomes negative resulting in a positive value of sed1, see Figure 3.3, under auxiliary buoy1.

$$sed1 = MAX(0, -sedbuoNP1) \tag{3.311}$$

Where:

$$sedbuoNP1 = k2NP * (\frac{powNP1}{powNP1 + k3NP^{k1NP}} - 0.5) \tag{3.312}$$

And:

$$powNP1 = MIN(myp1, myn1)^{k1NP} \tag{3.313}$$

Where:

Name	Comment	Unit	Type*)
k1NP	Exponent, sedimentation& buoyancy, PC1&PC3	n.u.	C
K2NP	Factor for sedimentation & buoyancy, PC1 & PC3	n.u.	C
k3NP	Shift from sedimentation to buoyancy, PC1 & PC3	n.u.	C
powNP1	Power function for limiting nutrient, Flagellate (PC1)	n.u.	A
myn1	Nitrogen function flagellates	n.u.	A
myp1	Phosphorous function flagellates	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

Sed3: N&P sedimentation function, cyanobacteria, n.u.

The sedimentation (downward movement) of the bacteria is increased by low internal N/C and P/C ratios of the bacteria. powNP3 will be positive but small and sedbuoNP3 becomes negative resulting in a positive value of sed3, see Figure 3.4 under auxiliary buou3.

$$sed3 = MAX(0, -sedbuoNP3) \tag{3.314}$$

Where:

$$sedbuoNP3 = k2NP * (\frac{powNP3}{powNP3 + k3NP^{k1NP}} - 0.5) \tag{3.315}$$

And:

$$powNP3 = MIN(myp3, myn3)^{k1NP} \tag{3.316}$$

Where:

Name	Comment	Unit	Type*)
k1NP	Exponent, sedimentation& buoyancy, PC1&PC3	n.u.	C
K2NP	Factor for sedimentation & buoyancy, PC1 & PC3	n.u.	C
k3NP	Shift from sedimentation to buoyancy, PC1 & PC3	n.u.	C
powNP3	Power function for limiting nutrient, cyanobacteria (PC3)	n.u.	A
myn3	Nitrogen function cyanobacteria	n.u.	A
myp3	Phosphorous function cyanobacteria	n.u.	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

SIPm3: PO_4-P in pore water, g P m^{-3}

$$SIPm3 = \frac{SIP}{(1 - dm) * vf * kds} \tag{3.317}$$

Where:

Name	Comment	Unit	Type*)
SIP	Sediment PO_4-P pool	g P m^{-2}	S
dm	Sediment dry matter	g DM gWW^{-1}	C
vf	Sediment bulk density	g ww cm^{-3}	C
Kds	Depth of modelled sediment layer	m	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

Smoot_T: Correction of reference temperature for diatoms, °C

Smoot_T is a function that makes a smoothing or rolling average of the daily insolation (PAR) on surface over a number of days ($T2_{days}$) defined by the user. This smoothing or rolling average is used to adjust the reference temperature of the max. specific growth rate of the diatoms, see auxiliary *myte2,* Equation (3.299).

The seasonal variation of temperature in the water follow the seasonal variation of the light (PAR) with a delay (1 month) depending of the amount of water (depth) to be heated up. In spring the temperature will be low compared to the daily PAR doze whereas in fall the temperature will be high compared to the daily PAR doze. The diatom reference temperature therefor has to change over the season.

In spring the diatoms blooms at low temperatures and disappear when the silicate is used up. During summer some silicate will be available however the diatom community has changed and another higher reference temperature is needed. In fall a secondary diatom bloom is sometimes seen after the erosion of the pycnocline. The diatom community is again adapted to lower temperatures and decreasing PAR.

Introducing Smoot_T is an attempt to make a seasonal adjustment of the specific growth with the water temperature and light as forcing.

One of two builtin functions can be used SMOOTING_AVERAGE or MOVING_AVERAGE can be used, see (MIKE by DHI 2011b). The latter function demands more memory and increases the CPU time slightly.

$$Smoot\_T = \frac{difT2}{maxI_0} * SMOOTHING\_AVERAGE(i_0, \frac{DT_{day}}{T2_{days}}) \tag{3.318}$$

Where:

Name	Comment	Unit	Type*)
difT2	Max variation in reference temp., diatom production	°C	C
$maxI_0$	Max average monthly i_o of year (July or Jan.)	mol photon $m^{-2}d^{-1}$	C
i_0	Light (PAR) at surface	mol photon $m^{-2}d^{-1}$	F
DT_{day}	AD time step in days, (normally between 5 min. to 1 h)	d	F
$T2_{days}$	No. of days in smoothing or rolling average function	d	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

SNHm3: NH4-N in sediment pore water, g N m^{-3}

$$SNHm3 = \frac{SNH}{(1 - dm) * vf * kds} \tag{3.319}$$

Where:

Name	Comment	Unit	Type*)
SNH	Sediment NH_4-N pool	g N m^{-2}	S
dm	Sediment dry matter	g DM gWW^{-1}	C
vf	Sediment bulk density	g ww cm^{-3}	C
Kds	Depth of modelled sediment layer	m	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

SNO3m3: NO_3-N in pore water of surface sediment layer (0-KDO2) , g N m^{-3}

$$SNO3m3 = \frac{SNO3}{(1 - dm) * vf * KDO2} \tag{3.320}$$

Where:

Name	Comment	Unit	Type*)
SNO3	Sediment NO_3-N pool	g N m^{-2}	S
dm	Sediment dry matter	g DM gWW^{-1}	C
vf	Sediment bulk density	g ww cm^{-3}	C
KDO2	Depth of O_2 penetration in sediment	m	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

sqdo: Oxygen function, n.u.

$$sqdo = \frac{DO^{ndo3}}{DO^{ndo3} + mdo3} \tag{3.321}$$

Where:

Name	Comment	Unit	Type*)
DO	Oxygen	g O_2 m^{-3}	S
ndo3	Exponent for DO in sqdo	n.u.	C
mdo3	Half-saturation constant DO	g O_2 m^{-3}	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

zk1: Light penetration (availability) in actual layer for flagellate production, m

$$zk1 = MIN(dz, MAX(0, \frac{\ln(i) - \ln(ik1)}{eta})) \tag{3.322}$$

Where:

Name	Comment	Unit	Type*)
i	Light (PAR) in actual layer	mol photon $m^{-2}d^{-1}$	A
ik1	Light saturation temp. corrected, Flagellate	mol photon $m^{-2}d^{-1}$	A
eta	Vertical light extinction in layer	m^{-1}	A
dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

zk2: Light penetration (availability) in actual layer for diatom production, m

$$zk1 = MIN(dz, MAX(0, \frac{\ln(i) - \ln(ik2)}{eta})) \tag{3.323}$$

Where:

Name	Comment	Unit	Type*)
i	Light (PAR) in actual layer	mol photon $m^{-2}d^{-1}$	A
Ik2	Light saturation temp. corrected, diatoms	mol photon $m^{-2}d^{-1}$	A
eta	Vertical light extinction in layer	m^{-1}	A
dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

zk3: Light penetration (availability) in actual layer for cyanobacteria production, m

$$zk1 = MIN(dz, MAX(0, \frac{\ln(i) - \ln(ik3)}{eta})) \tag{3.324}$$

Where:

Name	Comment	Unit	Type*)
i	Light (PAR) in actual layer	mol photon $m^{-2}d^{-1}$	A
Ik3	Light saturation temp. corrected, cyanobacteria	mol photon $m^{-2}d^{-1}$	A
eta	Vertical light extinction in layer	m^{-1}	A
dz	Height of actual water layer	m	F

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

unh1: potential NH_4 uptake by flagellates, g N m^{-3} d^{-1}

$$unh1 = PC1 * maxupnh * \frac{NH4}{NH4 + hupnh} \tag{3.325}$$

Where:

Name	Comment	Unit	Type*)
PC1	Flagellate C	g C m^{-3}	S
maxupnh	Max. N uptake by phytoplankton during N limitation	g N g $C^{-1}d^{-1}$	C
hupnh	Half-saturation constant for NH_4, phytoplankton uptake	g N m^{-3}	C
NH4	NH_4-N in water	g N m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

unh2: potential NH_4 uptake by diatoms, g N m^{-3} d^{-1}

$$unh2 = PC2 * pda2 * maxupnh * \frac{NH4}{NH4 + hupnh * pdb2} \tag{3.326}$$

Where:

$$pda2 = (\frac{esd2}{esd1})^{kbt1} \tag{3.327}$$

And:

$$pdb2 = (\frac{esd2}{esd1})^{kbt2} \tag{3.328}$$

Where:

Name	Comment	Unit	Type*)
PC2	Diatom C	g C m^{-3}	S
maxupnh	Max. N uptake by flagellates during N limitation	g N g $C^{-1}d^{-1}$	C
hupnh	Half-saturation constant for NH_4, phytoplankton uptake	g N m^{-3}	C
NH4	NH_4-N in water	g N m^{-3}	S
pda2	Ratio, nutrient uptake, Diatom : Flagellate	n.u.	A
pdb2	Ratio, half saturation conc. Diatom: Flagellate	n.u.	A
esd1	Equivalent spherical diameter, flagellates	µm	C

Name	Comment	Unit	Type*)
esd2	Equivalent spherical diameter, Diatom	µm	C
kbet1	Exponent 1 for potential uptake of nutrients	n.u.	C
kbet2	Exponent 2 for half saturation conc.	n.u.	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

unh3: Potential NH4 uptake by cyanobacteria, g N m^{-3} d^{-1}

$$unh3 = PC3 * pda3 * maxupnh * \frac{NH4}{NH4 + hupnh * pdb3} \tag{3.329}$$

Where:

$$pda3 = (\frac{esd3}{esd1})^{kbt1} \tag{3.330}$$

And:

$$pdb3 = (\frac{esd3}{esd1})^{kbt2} \tag{3.331}$$

Where:

Name	Comment	Unit	Type*)
PC3	Cyanobacteria C	g C m^{-3}	S
maxupnh	Max. N uptake by flagellates during N limitation	g N g C^{-1}d^{-1}	C
hupnh	Half-saturation constant for NH$_4$, phytoplankton uptake	g N m^{-3}	C
NH4	NH$_4$-N in water	g N m^{-3}	S
pda3	Ratio, nutrient uptake, Cyanobacteria : Flagellate	n.u.	A
pdb3	Ratio, half saturation conc. Cyanobacteria: Flagellate	n.u.	A
esd1	Equivalent spherical diameter, flagellates	µm	C
esd3	Equivalent spherical diameter, Cyanobacteria	µm	C
kbet1	Exponent 1 for potential uptake of nutrients	n.u.	C
kbet2	Exponent 2 for half saturation conc.	n.u.	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

un31: Potential NO$_3$ uptake by flagellate, g N m^{-3} d^{-1}

$$un31 = PC1 * maxupn3 * \frac{NO3}{NO3 + hupn3} \quad (3.332)$$

Where:

Name	Comment	Unit	Type*)
PC1	Flagellate C	g C m-3	S
maxupn3	Max. NO3 uptake by phytoplankton during N limitation	g N g $C^{-1}d^{-1}$	C
hupnh3	Half-saturation constant for NO3, phytoplankton uptake	g N m^{-3}	C
NO3	NO3-N in water	g N m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

un32: Potential NO_3 uptake by diatoms, g N m^{-3} d^{-1}

$$un32 = PC2 * pda2 * maxupn3 * \frac{NO3}{NO3 + hupn3 * pdb2} \quad (3.333)$$

Where:

$$pda2 = (\frac{esd2}{esd1})^{kbt1} \quad (3.334)$$

And:

$$pdb2 = (\frac{esd2}{esd1})^{kbt2} \quad (3.335)$$

Where:

Name	Comment	Unit	Type*)
PC2	Diatom C	g C m^{-3}	S
maxupn3	Max. NO_3 uptake by flagellates during N limitation	g N g $C^{-1}d^{-1}$	C
hupn3	Half-saturation constant for NO_3, phytoplankton uptake	g N m^{-3}	C
NO3	NO_3-N in water	g N m^{-3}	S
pda2	Ratio, nutrient uptake, Diatom : Flagellate	n.u.	A
pdb2	Ratio, half saturation conc. Diatom: Flagellate	n.u.	A
esd1	Equivalent spherical diameter, flagellates	µm	C
esd2	Equivalent spherical diameter, Diatom	µm	C

Name	Comment	Unit	Type*)
kbet1	Exponent 1 for potential uptake of nutrients	n.u.	C
kbet2	Exponent 2 for half saturation conc.	n.u.	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

un33: Potential NH$_4$ uptake by cyanobacteria, g N m^{-3} d^{-1}

$$un33 = PC3 * pda3 * maxupn3 * \frac{NO3}{NO3 + hupn3 * pdb3} \tag{3.336}$$

Where:

And:

$$pda3 = (\frac{esd3}{esd1})^{kbt1} \tag{3.337}$$

$$pdb3 = (\frac{esd3}{esd1})^{kbt2} \tag{3.338}$$

Where:

Name	Comment	Unit	Type*)
PC3	Cyanobacteria C	g C m^{-3}	S
maxupn3	Max. NO$_3$ uptake by flagellates during N limitation	g N g C^{-1}d^{-1}	C
Hupn3	Half-saturation constant for NO$_3$, phytoplankton uptake	g N m^{-3}	C
NO3	NO$_3$-N in water	g N m^{-3}	S
pda3	Ratio, nutrient uptake, Cyanobacteria : Flagellate	n.u.	A
pdb3	Ratio, half saturation conc. Cyanobacteria: Flagellate	n.u.	A
esd1	Equivalent spherical diameter, flagellates	µm	C
esd3	Equivalent spherical diameter, Cyanobacteria	µm	C
kbet1	Exponent 1 for potential uptake of nutrients	n.u.	C
kbet2	Exponent 2 for half saturation conc.	n.u.	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

upo1: Potential PO_4 uptake by flagellate, g P m^{-3} d^{-1}

$$upo1 = PC1 * maxupip * \frac{PO4}{PO4 + hupp} \tag{3.339}$$

Where:

Name	Comment	Unit	Type*)
PC1	Flagellate C	g C m^{-3}	S
maxupip	Max. P uptake by phytoplankton during P limitation	g P g $C^{-1}d^{-1}$	C
hupip	Half-saturation constant for PO_4, phytoplankton uptake	g P m^{-3}	C
PO4	PO_4-P in water	g P m^{-3}	S

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

upo2: Potential PO_4 uptake by diatoms, g P m^{-3} d^{-1}

$$upo2 = PC2 * pda2 * maxupip * \frac{PO4}{PO4 + hupp * pdb2} \tag{3.340}$$

Where:

$$pda2 = (\frac{esd2}{esd1})^{kbt1} \tag{3.341}$$

And:

$$pdb2 = (\frac{esd2}{esd1})^{kbt2} \tag{3.342}$$

Where:

Name	Comment	Unit	Type*)
PC2	Diatom C	g C m^{-3}	S
maxupip	Max. PO_4 uptake by flagellates during P limitation	g P g $C^{-1}d^{-1}$	C
hupp	Half-saturation constant for PO_4, phytoplankton uptake	g P m^{-3}	C
PO4	PO_4-P in water	g P m^{-3}	S
pda2	Ratio, nutrient uptake, Diatom : Flagellate	n.u.	A
pdb2	Ratio, half saturation conc. Diatom: Flagellate	n.u.	A
esd1	Equivalent spherical diameter, flagellates	µm	C

Name	Comment	Unit	Type*)
esd2	Equivalent spherical diameter, Diatom	µm	C
kbet1	Exponent 1 for potential uptake of nutrients	n.u.	C
kbet2	Exponent 2 for half saturation conc.	n.u.	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

upo3: Potential PO_4 uptake by cyanobacteria, g P m^{-3} d^{-1}

$$upo3 = PC3 * pda3 * maxupip * \frac{PO4}{PO4 + hupp * pdb3} \tag{3.343}$$

Where:

$$pda3 = (\frac{esd3}{esd1})^{kbt1} \tag{3.344}$$

And:

$$pdb3 = (\frac{esd3}{esd1})^{kbt2} \tag{3.345}$$

Where:

Name	Comment	Unit	Type*)
PC3	Cyanobacteria C	g C m^{-3}	S
maxupip	Max. PO_4 uptake by flagellates during P limitation	g P g $C^{-1}d^{-1}$	C
hupp	Half-saturation constant for PO_4, phytoplankton uptake	g P m^{-3}	C
PO4	PO_4-P in water	g P m^{-3}	S
pda3	Ratio, nutrient uptake, Cyanobacteria : Flagellate	n.u.	A
pdb3	Ratio, half saturation conc. Cyanobacteria: Flagellate	n.u.	A
esd1	Equivalent spherical diameter, flagellates	µm	C
esd3	Equivalent spherical diameter, Cyanobacteria	µm	C
kbet1	Exponent 1 for potential uptake of nutrients	n.u.	C
kbet2	Exponent 2 for half saturation conc.	n.u.	C

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

usi2: Potential Si uptake by diatoms, g Si m^{-3} d^{-1}

$$usi2 = PC2 * maxupsi * \frac{Six}{Six + hupsi} \tag{3.346}$$

Where:

$$six = Si - Simin \tag{3.347}$$

Where:

Name	Comment	Unit	Type*)
PC2	Flagellate C	g C m^{-3}	S
maxupsi	Max. Si uptake by phytoplankton during Si limitation	g Si g $C^{-1}d^{-1}$	C
hupsi	Half-saturation constant for Si, diatom uptake	g Si m^{-3}	C
Six	available Si for diatoms, (Si-Simin) >=0, Si for uptake PC2	g Si m^{-3}	A
Si	Si in water	g Si m^{-3}	S
Simin	Si not available for PC2	g Si m^{-3}	A

*) S: State variable, F: Forcing, C: Constant, P: Process in differential equation, P1: Help process, A: Auxiliary help process.

4 Data Requirements

- Basic Model Parameters
    - Model grid size and extent
    - Time step and length of simulation
    - Type of output required and its frequency

- Bathymetry and Hydrodynamic Input

- Combined Advection-Dispersion Model
    - Dispersion coefficients

- Initial Conditions
    - Concentration of parameters

- Boundary Conditions
    - Concentration of parameters

- Pollution Sources
    - Discharge magnitudes and concentration of parameters

- Process Rates
    - Size of coefficients governing the process rates. Some of these coefficients can be determined by calibration. Others will be based on literature values or found from actual measurements and laboratory tests.

- Forcings

- Data sets of photosynthetic active light (PAR) (E/m^2/day)

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